THE ECOLOGY OF WAIKOROPUPU SPRINGS

A thesis presented for the degree of Ph.D.
in Zoology in the University of Canterbury,
Christchurch, New Zealand

by

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1974

FRONTISPIECE: Aerial view of Waikoropupu Springs and surrounding area. The Springs discharge via the Springs outflow into the Waikoropupu River and then the Takaka River into Golden Bay (upper right). Fish Creek, partly fed by small springs (extreme lower right), enters the Springs outflow just below the Springs.

Photo: V.C. Browne.

"(Sources rhéocrènes et sources limnocrènes) sont des milieux s'apparentant, au point de vue hydrobiologique, au domaine souterrain"

(Dussart 1966)

CONTENTS

LIST OF TABLES

LIST OF FIGURES

PART 3

PART 4 (printed)

LIST OF PLATES

Underwater photographs were taken with a Nikonos II 35 mm camera (f/2.5 lens) and natural lighting. Lack of contrast in directly-overhead shots taken underwater, also observed by Wood (1963), was partly overcome by the use of a high contrast film ADOX KB 17 (40 ASA uprated to 80 ASA). AGFACOLOR Special Negative Film CN S (exposed as 80 ASA) was used for colour work.

GENERAL INTRODUCTION

Springs have long been important to man for several reasons: as a source of palatable drinking water containing few bacteria, as a source of mineral water for internal therapy or bathing, and as a general water supply that does not freeze or run dry. A number of springs e.g. the fountain of Castalia at Delphi, Greece (Milner 1880) assumed a religious significance because it was believed that fluctuations in their discharge could be used to foretell the future. Springs are also important because they are the sources of many rivers, such as the Thames in England which flows from Seven Springs in Gloucester (Milner 1880).

Springs and resurgences are formed where ground water comes to the surface. Ground water outlets are found in many locations: on flat or rolling land, at the foot of mountains, in lakes or at sea. Silver Springs, U.S.A. (Odum 1957a) and Waikoropupu Springs, New Zealand are examples of ground water outlets on flat land whereas the Fountain of Vaucluse, Southern France (Cousteau and Dumas 1954) and the Riwaka Resurgence, New Zealand are examples of ground water outlets at the foot of mountains. Cold springs have been reported in many lakes, including Lake Wigry, Poland (Demel 1923); Ryûran-tan, Taiwan (Miyadi 1939); the Lac d'Annecy, France (Juget 1958) and Lake Grasmere, Canterbury, New Zealand (Stout 1971). Submarine springs are known off the coast of Florida (Brooks 1961) and in many other areas.

Explorations by cavers and SCUBA divers have shown that there are two types of ground water outlets: one type has a cavity that empties via a siphon, as with the famous Fountain of Vaucluse, Southern France (Cousteau and Dumas 1954) or the

Riwaka Resurgence, New Zealand (Nelson Underwater Club, pers. comm.); the other type has neither cavity nor siphon, as is the case at Wakulla Springs, U.S.A. (Olsen 1958) or the Source de la Bèze, Dijon, France (Dussart 1966).

There has been some confusion in New Zealand over the use of the terms "spring" and "resurgence". However, the term "resurgents" applies to the outlets of large underground rivers (Vandel 1965). Resurgences are not as constant in their discharge as springs (Dussart 1966) and are not necessarily of constant temperature. Although a number of resurgences in the South Island have been investigated by the author, this thesis is limited to studies of springs.

Several methods of classifying springs have been proposed, based on temperature, water discharge, shape or water chemistry. Tuxen (1944), working on hot springs in Iceland, classified springs according to temperature as cold, tepid or hot. Meinzer (1927) classed springs as first, second or third order according to their water discharge. Bornhauser (1913) classified springs according to shape as limnocrene or rheocrene, and Thienemann (1925) extended this classification to include the helocrene. Whitford (1956) defined six types of spring on the basis of water chemistry and algal flora. These methods of classification of springs are discussed further in Part 1 and in the General Discussion.

The flora of cold springs has received little attention. Whitford (1956) described the algae in many springs in Florida, U.S.A. and Round (1960, 1965) and Eaton (1967 unpublished, cited by Round 1968) listed diatoms in several cold springs in England. Morton (1942a,b; 1944) recorded the mosses and higher plants in springs in Hallstatt, Austria, and Pennak (1953) referred to watercress as a plant characteristic of springs. In addition, several authors have briefly mentioned the flora of cold springs e.g. Kühn (1940) in Austria; Davidson and Wilding (1943), Odum (1957 a,b), Teal (1957), Minckley (1963) and Tilly (1968) in the United States; and Thorup (1966) in Denmark.

Most studies of cold springs have concentrated on their fauna. The earlier studies in Europe listed the invertebrate present (Thienemann 1912, 1926, 1931, 1950; Kühn 1940) and commented on "glacial relicts" (Bornhauser 1913; Thienemann 1925; Hubault 1927; Carpenter 1928; Nielsen 1950 a,b; Botosaneanu and Negrea 1961) and "phreatic" fauna (Thienemann 1912, 1925; Vandel 1920). Cold springs often provide almost constant conditions of water temperature, discharge and chemistry in which relationships between life histories of aquatic invertebrates and environmental variables such as light can be studied. Nielsen (1942) described the life histories of 15 species of Trichoptera in cold springs in Denmark and Thorup (1963) described the life histories of eight species of insect, an isopod and a mollusc, also in Danish springs. Gower (1965, 1967) described the life histories of two species of Trichoptera in cultivated watercress beds fed by cold springs.

The distribution of animals in Danish cold springs, and their animal communities, was considered by Thorup (1966) in terms of a biotope with its associated biocoenosis. Biotopes (Dahl 1908) were originally defined as "Gelände- und Gewässerarten" - the kinds of terrestrial and aquatic environments in which organisms occurred (Hutchinson 1967). The term biotope has since been used in many ways but the present study will use it in the restricted sense of European limnologists such as Berg (1948) and Thorup (1966). They define a biotope as an area of uniform substrate and water velocity that has associated with it a well-developed plant and animal community. This plant and animal community is termed a biocoenosis (Mobius 1877 cited by Hutchinson 1967) and includes characteristic species of plants, termed exclusive species by Poore (1955), and characteristic species of animals (Berg 1948).

Quantitative work on the fauna and, to a lesser extent, the flora of cold springs has been carried out principally in the United States. Davidson and Wilding (1943) determined the "food grade" of a small spring in Washington and Pennak (1953) described the typical fauna of a cold spring in the United States. Odum (1957a) presented data on biomass and energy flow in the large, subtropical Silver Springs and estimated primary productivity in a number of other Florida springs (Odum 1957b). Teal (1957) and Tilly (1968) produced energy flow diagrams for small temperate springs in Massachusetts and Iowa respectively, and Wilhm (1970) described the trophic structure of a cold spring near Tennessee.

Springbrooks, which are the outflows of springs, possess many of the features of springs but their temperature is not as constant. In North American springbrooks, the life histories of aquatic invertebrates and seasonal changes in their numbers have been investigated by Noel (1954), Minshall (1968), Stern and Stern (1969) and Pearson and Kramer (1972). Several studies have shown that springbrooks are largely dependent on allochthonous detritus as their energy source (Minckley 1963; Minshall 1967; Stern and Stern 1969). In Denmark, the distribution of invertebrates in a springbrook was investigated (Thorup 1970b) and the effect of a flood on the springbrook assessed (Thorup 1970a). The present study is restricted to the spring source, where the spring water issues from the ground, and to a short distance downstream of the source. Typical spring communities are restricted to this area (Pennak 1953).

In New Zealand, a ground water outlet of fairly constant discharge and temperature on flat or rolling land is termed a "spring", whether referring to a "hot spring" or a "cold spring". Although a number of chemical and biological studies have been carried out on hot springs in New Zealand, the cold springs have been almost neglected. The only published studies on cold springs are those of Henderson (1928, 1941) on the geology of Waikoropupu Springs; Johnstone (1972) on the limnology of Western Springs, Auckland; Petty (1972) on the hydrology and chemistry of 12 cold springs in the Auckland region, and Marshall (1973) on a survey of the fauna of the Avonhead Springs, Christchurch. Some unpublished information on the hydrology of cold springs is held by the Water and Soil Division, Ministry of Works and the New Zealand Geological Survey.

Waikoropupu Springs, the subject of the present study (see Frontispiece), are the largest cold springs in New Zealand and one of the largest cold springs in the world. They are located at Takaka in North-West Nelson. The geology of the surrounding area and the possible origin of the Springs water were discussed by Henderson (1928, 1941) but, until 1970, no further studies were undertaken. The Springs were therefore selected as the site for the present study, which examined a number of aspects of their ecology.

"Waikoropupu" is a Maori word meaning "bubbling (boiling) fresh water". The Springs were known to the Maoris

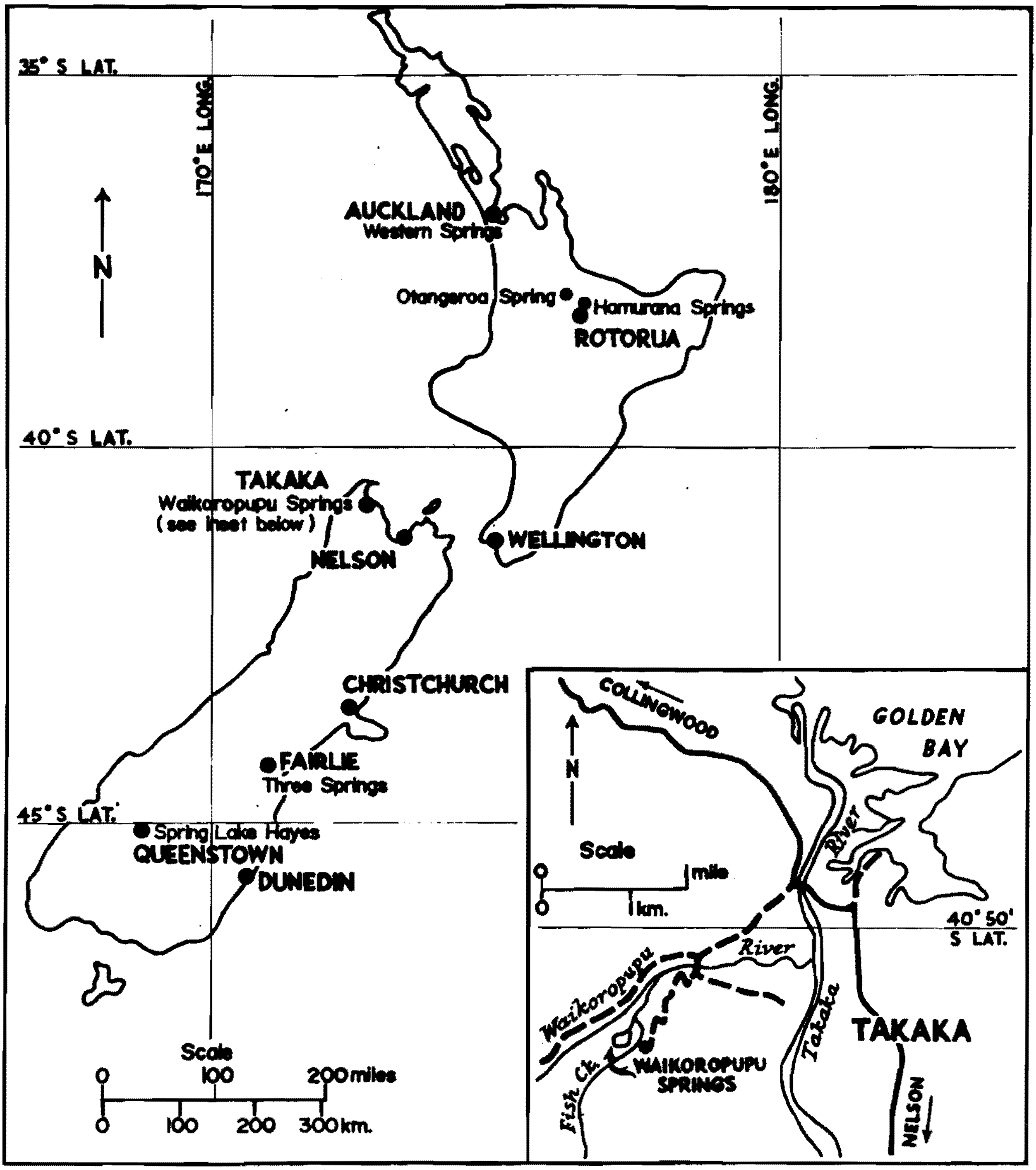

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FIG GI.1: Map of New Zealand showing location of the cold springs studied. Inset shows location of Waikoropupu Springs.

(Washbourn 1939), but it was the activities of European man that first disturbed the area. About 1900, gold was mined to the east of the Springs (H. M. Campbell, pers. comm.) and the forest surrounding the Springs was cleared and partly converted to grass for pasture. Today, cattle that graze the pasture have access to the Springs at certain times of the year. Although the Springs are located on private property, permission for public entry is not required and they are visited by several thousand people each year, mainly in summer. Visitors appear to have little impact on the Springs. Fewer than fifty people dive in the Springs each year and they also have no observable effect on them. The Springs have recently been selected as a Project Aqua site for conservation under the International Biological Programme (Luther and Rzóska 1971; Appendix 1). Purchase of the Springs by the Crown is being negotiated and it is hoped that they will become a scientific reserve, any development of the area being kept to a minimum.

Although the present study is concerned primarily with Waikoropupu Springs it includes data on five other cold springs in New Zealand, the locations of which are shown in Fig. GI.1. All these cold springs were recorded by the New Zealand Department of Lands and Survey (1968) except for Otangeroa Springs at Putaruru. Hamurana Springs, Rotorua and Otangeroa Springs were included in the study because they are, in terms of water discharge, the largest cold springs in New Zealand after Waikoropupu Springs. The other cold springs studied, i.e. Three Springs, Fairlie; Western Springs, Auckland; and a spring at Lake Hayes, Queenstown, all have much lower rates of discharge.

Hamurana Springs on the shore of Lake Rotorua are a spawning ground for the introduced rainbow trout (*Salmo gairdneri*) and have been developed as a tourist attraction with introduced conifers, a deer park and a bird sanctuary. The water chemistry of the springs was mentioned by Fish (1969). Otangeroa Springs rise in undulating farmland near Putaruru and have not been previously studied. Three Springs are located in farmland at Kimbell near Fairlie. The largest spring, which is near the main highway, has been tapped to provide water for the town of Fairlie and is the only one of the three springs referred to in the present study. The hydrogeology of Three Springs was studied by Oborn (1963 unpublished). Western Springs, a small spring-fed lake in the centre of Auckland, has been studied by the Zoology Department, University of Auckland (1962 unpublished) and Johnstone (1969 unpublished, 1972). The present study considered only the largest spring and its inflow to the lake and not the lake itself, which becomes thermally stratified in summer (Johnstone 1972). The Spring at Lake Hayes rises in a grove of introduced trees on a low terrace near the lake and flows a short distance through open country before discharging into the lake. It was mentioned by Jolly (1952) in a study of Lake Hayes.

The present study was concerned primarily with the plants and animals of Waikoropupu Springs but the biological features of these other New Zealand cold springs were considered. The physical and chemical features of the springs were also investigated.

PART 1

PHYSICAL AND CHEMICAL FEATURES

INTRODUCTION

There have been few detailed studies of the water temperature, discharge or water chemistry of springs. Information on the hydrology of large cold springs in the United States was given by Meinzer (1927) and of cold springs in Florida by Ferguson, Lingham, Love and Vernon (1947). Kühn (1940) recorded physical and chemical data for seven springs in Austria and Nielsen (1942) and Berg (1951) noted water discharge and current rate for many cold springs in Denmark. In the Auckland region of New Zealand, Petty (1972) recorded water temperature, discharge and chemistry for 78 springs (of which 12 were cold springs).

There are four methods of classifying springs, based on temperature, discharge, shape and chemistry. Tuxen (1944) distinguished springs of varying temperature (heterothermal springs) and springs of constant temperature (homothermal springs). He further classified springs as cold, tepid or hot; defining cold springs as those with temperatures below or at the annual mean air temperature of the locality. In New Zealand, this definition would apply to springs at sea level with water temperatures from about 9°C (near Invercargill) to 15°C (near Auckland) (New Zealand Department of Statistics 1972) although colder springs would be expected at higher altitudes.

Springs were classified by Meinzer (1927) according to water discharge: "first order" when average discharge exceeded 100 cusecs (2.8 m^3/s), "second order" when average discharge was between 10 and 100 cusecs (0.28-2.8 m^3/s) and "third order" when average discharge was less than 10 cusecs (0.28 m^3/s).

Bornhauser (1913) classified springs as limnocrene or rheocrene and several later authors (e.g. Thienemann 1925;

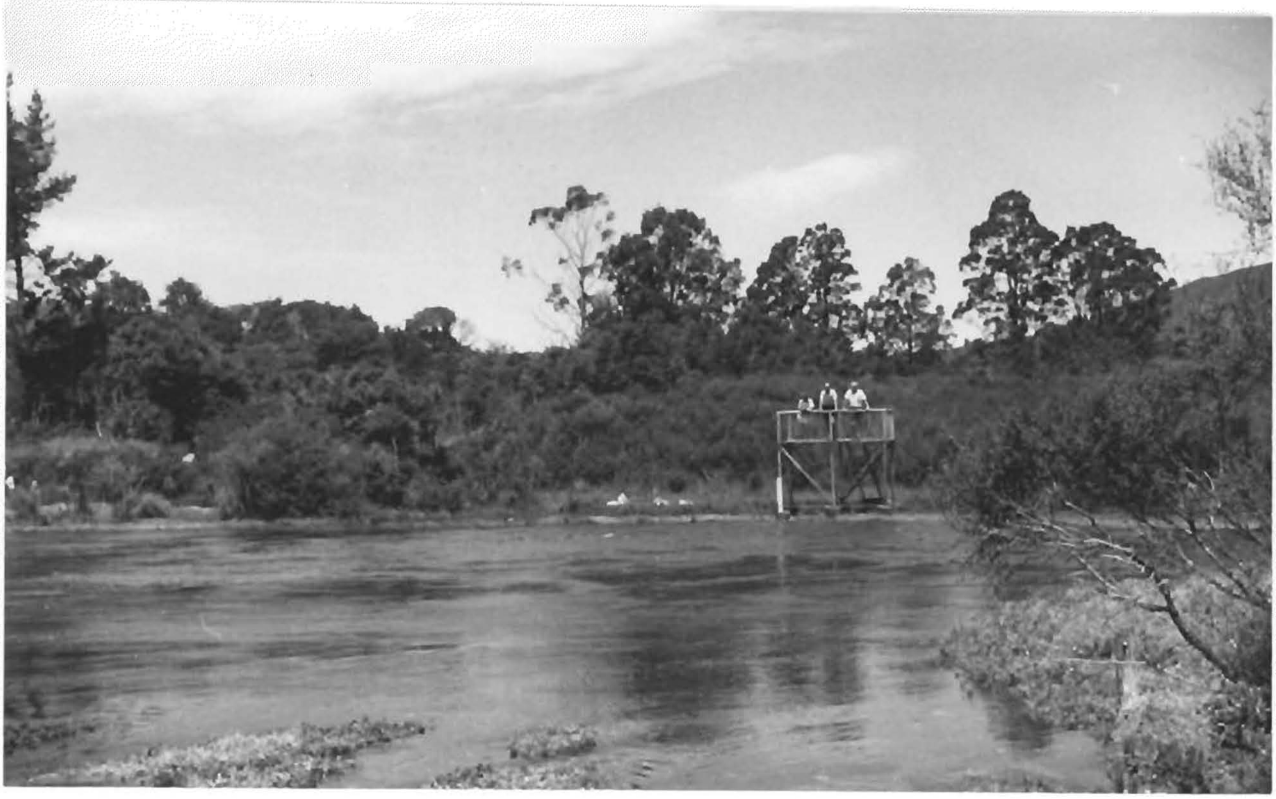


PLATE 1.1: The Main Spring, Waikoropupu Springs from downstream (true left bank). The Public Viewing Stand and the dome on the surface of the water, caused by discharge from the "principal" vent, can be seen in the centre. Photo: G.C. Wells

Carpenter 1928; Tuxen 1944; Hesse, Allee and Schmidt 1951) have described springs as limnocrene, rheocrene or helocrene. The water from a limnocrene (Gk. limne-pond, krene-spring) forms a basin round the head, in which it gathers before flowing away. Water from a rheocrene (Gk. rheo-to flow) issues from one or more heads at a place where it has no opportunity of forming a basin before running off. Water from a helocrene (Gk. helos-marsh) appears with no distinct head over a large swampy area (Tuxen 1944).

Whitford (1956) recognised six types of spring in Florida, U.S.A. on the basis of chemical composition and algal flora: soft freshwater; hard freshwater; oligohaline; mesohaline; mesohaline-sulphide and sulphide.

Waikoropupu Springs are a cold limnocrene (Plate 1.1). The earliest descriptions of these Springs were by the geologists Park (1890) and Bell, Webb and Clarke (1907). Bell *et al* wrote that "the spring rises with strong ebullition forming a pool of beautifully clear water, some 5 chains [100 m] long by 3 chains [60 m] wide, and is said to have constant volume unaffected by the heaviest rain". For the purpose of this study, the pool referred to by Bell *et al* (1907) was called the Main Spring and the smaller adjacent spring, which discharges through gravel, was called the Dancing Sands. Henderson (1928, 1941) discussed the geology of the Springs in some detail.

A. PHYSICAL FEATURES

LOCATION

Waikoropupu Springs are situated in the Takaka Valley, Nelson Province, New Zealand (grid reference NZMS 1/S8/171819) (Fig. GI.1), 120 km by road from the city of Nelson. The Springs are about 14 m above sea level. The outflow from the

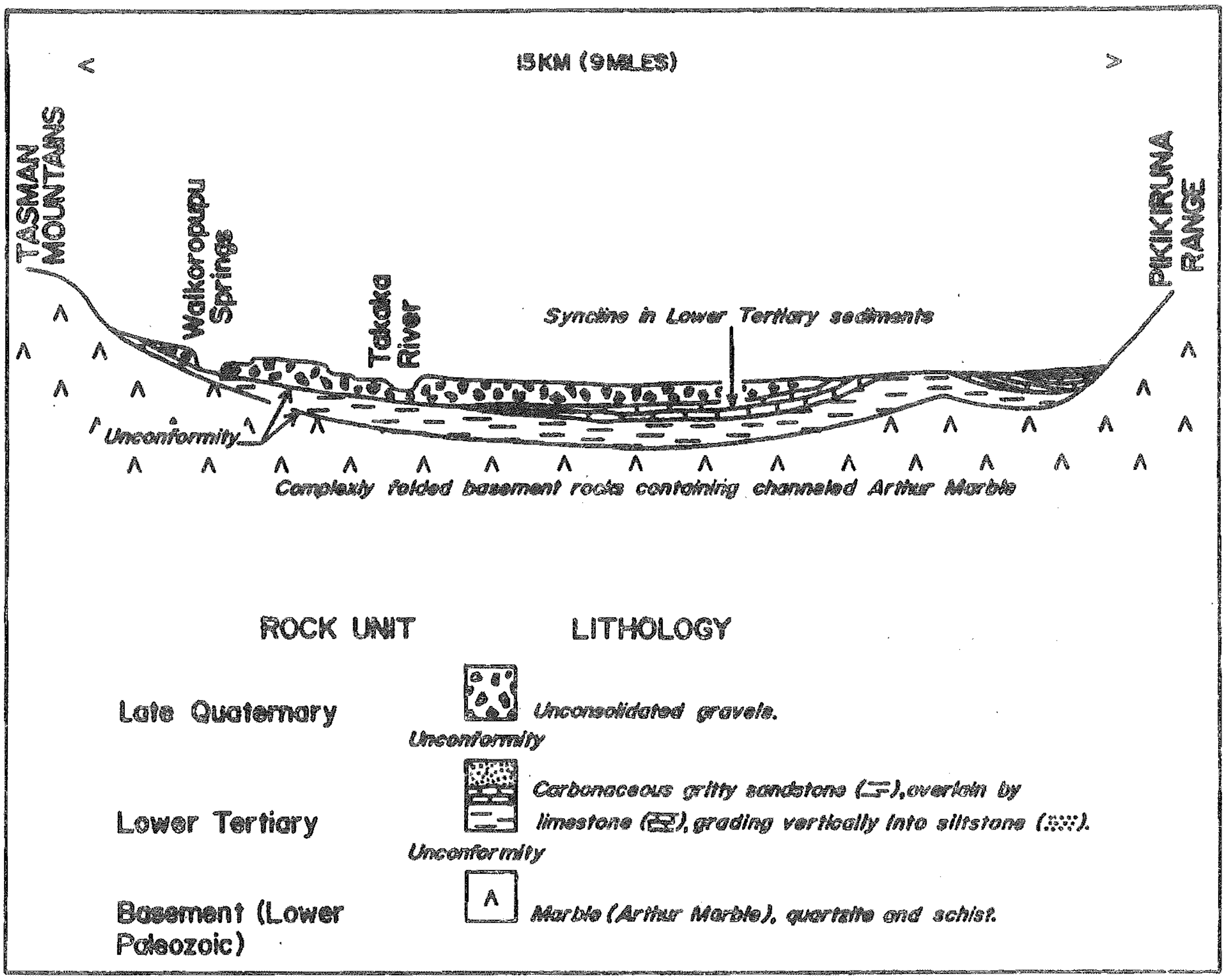


FIG. 1.1: Diagrammatic geological cross-section of the Takaka Valley. (Modified from Grindley 1961).

Springs joins the Waikoropupu River, a western tributary of the Takaka River which in turn flows into Golden Bay, 6 km from the Springs. In addition, two very small springs lie 240 m south-west of Waikoropupu Springs (Frontispiece) and discharge into Fish Creek, a tributary of the Waikoropupu Springs outflow (see map accompanying Appendix 1). These small springs are not considered in this study.

GEOLOGY OF THE AREA

The geology of the Takaka Valley (Grindley 1961) can be divided into three units by unconformities: basement rocks of dominantly Lower Paleozoic sediments, Lower Tertiary sediments and Late Quaternary gravels (Fig. 1.1). The basement sediments consist of complexly folded marble (Arthur Marble), quartzite and schist, and form the mountains surrounding the valley. The Arthur Marble crops out extensively and contains numerous channels and sinkholes. The Lower Tertiary sediments consist of carbonaceous (gritty) sandstone overlain by limestone which in turn is overlain by siltstone. They are gently folded into a syncline and are largely obscured by the Late Quaternary gravels which fill the floor of the Takaka Valley. Waikoropupu Springs are situated on the western flank of the syncline. The Main Spring discharges through carbonaceous gritty sandstone and the Dancing Sands discharge through the Late Quaternary gravels overlying the sandstone.

Henderson (1928) undertook a detailed study of the geology of the area adjacent to Waikoropupu Springs. He considered the Takaka Valley to be an artesian basin with channelled marble as the porous bed and with the schist, quartzite and Lower Tertiary sediments forming an impervious cap. The only known discharges from this basin are in the Waikoropupu Valley. It is probable that here the Arthur Marble rises close to the surface allowing discharge of water under pressure. The water may have initially broken through the impermeable cap along a zone of weakness such as a fault.

ORIGIN OF THE SPRINGS WATER

Park (1890), Bell *et al* (1907) and Henderson (1928, 1941) considered that the Springs water originated from the Takaka River at a point 10 miles (16 km) from the sea (NZMS 1/S8/218670). Below this point the river bed is frequently dry. Water flows into the Arthur Marble close to the surface in this area and then 8-10 miles (13-16 km) through an underground channel or series of channels to the Springs (Henderson 1928). Recent investigations by the Water and Soil Division, Ministry of Works, Nelson (pers. comm.) have confirmed that the Takaka River, near the point previously suggested, is the major source of water for the Springs, but that there are also other minor sources.

It is not known how long water is usually underground before it is discharged from Waikoropupu Springs. However the water has had sufficient time to equilibrate with the temperature of the containing beds (see section on water temperature, below) and dissolve salts from them, as water from Waikoropupu Springs has a higher level of dissolved salts (374 g/m^3-Main Spring) than water from the Takaka River (83 g/m^3) (sampled at NZMS 1/S8/207773 on 26 January 1970 and analysed by M.E.U. Taylor (pers. comm.)).

Using methods such as isotopic analysis, investigations are being continued by the Water and Soil Division, Ministry of Works, Nelson and the Institute of Nuclear Sciences, D.S.I.R., Wellington.

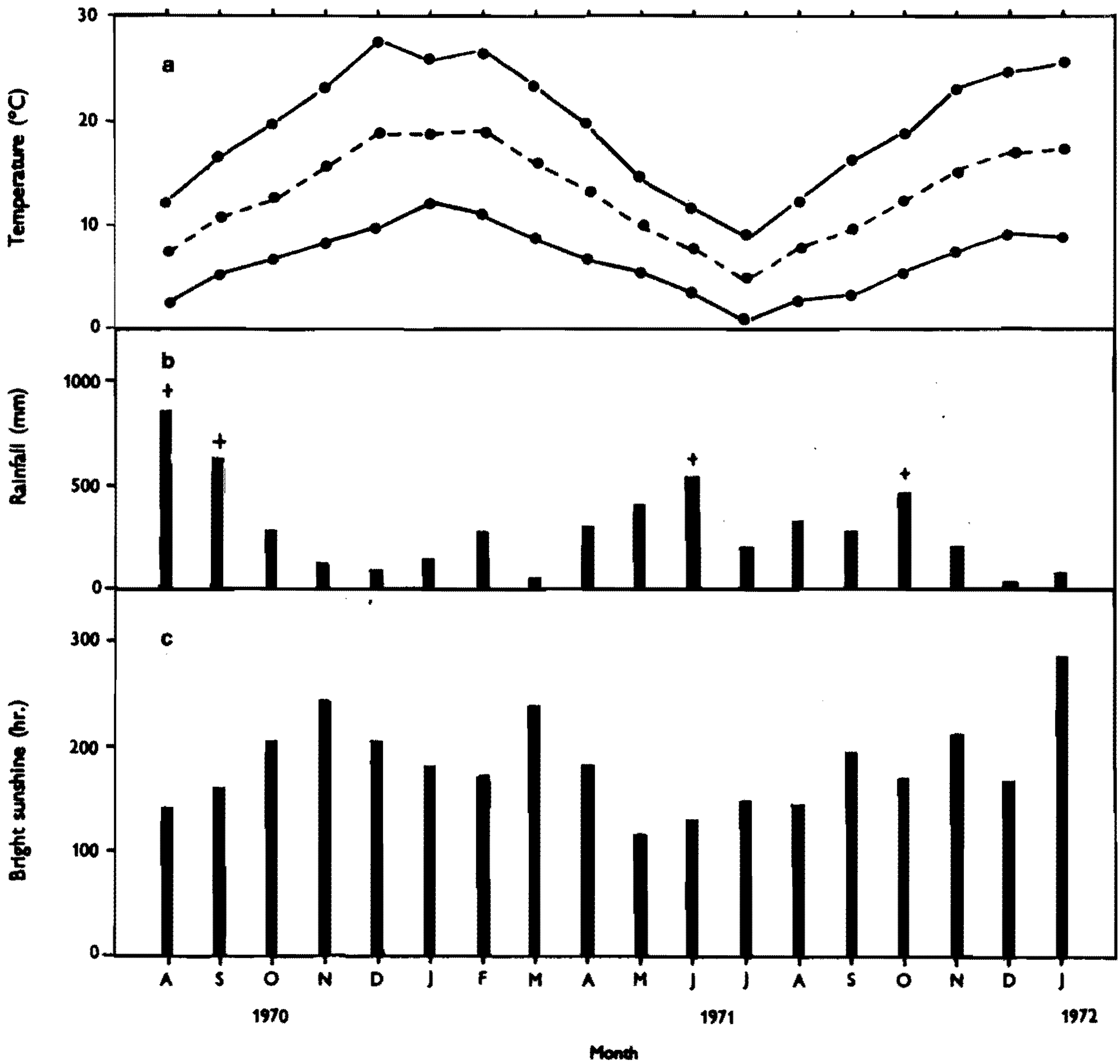


FIG. 1.2: Climatic data for the lower Takaka Valley. Refer to text for location of climate stations.
a. Monthly mean air temperature. Solid lines join maximum and minimum temperatures; dotted lines join mean temperatures.
b. Monthly total rainfall. + indicates that rainfall exceeded that recorded.
c. Monthly total bright sunshine.

CLIMATE

Since there is no meteorological station in the lower Takaka Valley, records were obtained from three different sites in the Valley: the Pupu Power House (NZMS 1/S8/141810) 3 km west-south-west of the Springs, Paton's Rock (S8/163893) 6 km north of the Springs and Takaka landing strip (S8/205745) 7 km south-south-east of the Springs. The climate of Waikoropupu Springs is influenced by Parapara Peak (altitude 1260 m, S8/083835) 8 km west-north-west of the Springs (see below). Climatic data recorded at the three sites over the period August 1970 - January 1972 are shown in Fig. 1.2.

Daily records of maximum and minimum air temperature were taken at the Power House where air temperatures would be similar to those at the Springs. Monthly maximum temperatures ranged from 8.8^{o}C to 27.6^{o}C and monthly minimum temperatures from 0.5^{o}C to 11.8^{o}C (Fig. 1.2a). Air temperature fell below 0^{o}C on 23 nights in 1971. On these nights, ground frosts probably occurred at the edge of the Springs and on the water-cress beds. The annual mean temperature for 1971 was 12.4^{o}C, which is close to the water temperature of Waikoropupu Springs (constant at 11.7^{o}C). Warmer than average conditions were experienced in Nelson Province in 1971 (New Zealand Meteorological Office data).

Daily measurements of rainfall were also made at the Power House. The raingauge overflowed whenever rainfall exceeded 185 mm in 24 hours, as in August 1970 (3 occasions), September 1970 (1 occasion), June 1971 (3 occasions) and October 1971 (2 occasions). The annual rainfall for 1971 was greater than 3132 mm. Rainfall at the Power House would probably be higher than that at Waikoropupu Springs because the Power House lies close to Parapara Peak which frequently collects cloud. Average annual rainfall at Waikoropupu Springs has been estimated at between about 80 in. (1940 mm) and 100 in. (2540 mm) (De Lisle and Kerr 1965). In both 1970 and 1971, rainfall was higher during winter than summer (Fig. 1.2b). Usually rainfall is fairly evenly spread between the seasons but long dry spells can occur in summer and early autumn (De Lisle and Kerr 1965).

Total bright sunshine was recorded by a glass sphere pyrheliograph located at Paton's Rock. Total bright sunshine for the year 1971 was 2147 hours, one of the highest totals in New Zealand. Readings at Paton's Rock would be higher than those at Waikoropupu Springs, since the cloud collected by Parapara Peak obscures the Springs area. Monthly total hours of bright sunshine were generally greatest during summer and least during winter (Fig. 1.2c).

No data are available on wind velocity at Waikoropupu Springs. Whereas the general flow over central New Zealand is from a westerly quarter, the topography of the Takaka district causes many local differences in wind direction. The Takaka Valley lies north to south but the Waikoropupu Valley lies north-east to south-west. Thus both valleys are sheltered from the prevailing westerly winds and from the easterly quarter. At Takaka (Fig. GI.1 inset), it is calm for 30 per cent of the time; 16 per cent of the time the winds are from the north-west, 15 per cent from the north-east and 9 per cent from the north, whereas only 20 per cent of the time the winds are from the south-east, south or south-west. Wind speed exceeds 17 knots (32 km/h) for only 13 per cent of the time (New Zealand Meteorological Office, unpublished data, based on observations at 0900, 1200 and 1500 hours, daily from 1936-1948).

WATER TEMPERATURE

Waikoropupu Springs

Nineteen readings were taken with a mercury thermometer at the main vents of both the Main Spring and the Dancing Sands over the period January 1970 to January 1971. On every occasion the temperature was 11.7°C. The maximum temperature recorded in fast flowing water near the shoreline of the Main Spring was 11.8°C but the temperature in fast flowing water 110 m downstream from the "principal" vent in the Main Spring reached 12.5°C on a hot sunny day.

New Zealand cold springs studied

Waikoropupu Springs (11.7°C), Hamurana Springs (12.1°C), Western Springs (15.7°C) and the Spring at Lake Hayes (10.3°C) have almost constant water temperatures at their sources (Table 1.1), reflecting the mean temperatures of the surrounding regions (11.8°C Nelson, 12.1°C Rotorua, 15.3°C Auckland and 10.1°C Queenstown respectively, New Zealand Department of Statistics 1972). This is also the case with many cold springs in other parts of the world e.g. Tyee Springs, Washington - 45°F (7.2°C) (Davidson and Wilding 1943); Root Spring, Massachusetts - 9.5°C (Teal 1957); Silver Springs, Florida - 22.2°C (Ferguson et al 1947). The constancy of temperature results from the spring water remaining underground long enough to equilibrate with the temperature of the containing beds.

WATER DISCHARGE

Waikoropupu Springs

"The discharge from the Pupu, though usually stated to be invariable, is by no means constant" (Henderson 1928).

TABLE 1.1: Water temperature and water discharge of Waikoropupu Springs and five other cold springs in New Zealand. Water temperatures marked with an asterisk are based on a single measurement. A dash denotes data not available.

Spring, location and grid reference	Water temperature (°C) (Mean and range)	Reference	Water discharge (m^3/s) (Mean and range)	Reference
Waikoropupu Springs, Takaka (NZMS1/S8/171819)	11.7 constant	Present study	about 11 (8.5–15)	Water & Soil Divn., Ministry of Works, Nelson (pers. comm.)
Hamurana Springs, Rotorua (NZMS1/N76/724172)	12.1 (11.2–13.0)	G.R. Fish (pers. comm.)	2.6 (2.5–3.0)	Water & Soil Divn., Ministry of Works, Hamilton (pers. comm.)
Otangeroa Springs, Putaruru (NZMS1/N75/190107, not marked)	13.0*	Water & Soil Divn., Ministry of Works, Hamilton (15 Jul 1971)	0.85 (0.82–0.93)	Water & Soil Divn., Ministry of Works, Hamilton (pers. comm.)
Three Springs, Kimbell, near Fairlie (NZMS1/S101/328956)	about 10 14.1*	Oborn 1963 unpublished Present study (15 Feb 1971)	0.58 (–)	Oborn 1963 unpublished
Western Springs, Auckland (NZMS1/N42/243585)	15.7 (15.6–15.9)	Johnstone 1972	0.21+ (0.18–0.24) 0.08	Johnstone 1972 Petty 1972
Spring at Lake Hayes, Queenstown (NZMS18/22/267378, not marked)	10.3 (10.0–10.6)	S. F. Mitchell and C. W. Burns (pers. comm.)	– (0.053–0.060)	S. F. Mitchell and C. W. Burns (pers. comm.)

+ "The actual inflow is much greater .... as there are springs all along the SW shore whose rates could not be measured" (Johnstone 1972).

Earlier discharge records, originally recorded in cusecs, confirm this statement (Table 1.2).

TABLE 1.2: Previously reported discharge of Waikoropupu Springs. A dash denotes data not available.

Reference	Date of measurement	Discharge cusecs	Discharge m^3/s	Notes
Henderson (1928)	March 1928	210	5.9	following prolonged drough
	—	680	19	"normal flow"
Water and Soil Divn., Ministry of Works, Nelson	29 Jun. 1953	407	12	discharges of Fish Ck and Waikoropupu R. subtracted frc Springs outflow gauging.
	23 Jul 1955	441	12	
	24 Jun 1956	461	13	
	15 Mar 1957	372	11	
	5 Mar 1959	294	8.3	

The gaugings reported by Henderson (1928) might have included Fish Creek and will not be considered here. Gaugings since 1953 recorded the discharge of the Main Spring and the Dancing Sands only and varied between 8.3 and 13 m^3/s.

In the present study, water discharge from the Springs was recorded from October 1970 to October 1972 by means of a staff gauge at a point 110 m downstream from the "principal" vent of the Main Spring where the spring outflow is 26 m wide (Fig. 1.3). Readings of the staff gauge were made daily until February 1971 and thereafter weekly. On the basis of these gaugings, the discharge of Waikoropupu Springs probably lies in the range 8.5-15 m^3/s, with an average discharge of about 11 m^3/s (Water and Soil Division, Ministry of Works, Nelson, pers. comm.).

Waikoropupu Springs have a more stable discharge, and hence more stable water velocities, than rivers in the surrounding area (Water and Soil Division, Ministry of Works, Nelson, pers. comm.). This is the case with many other springs (Berg 1951; Odum 1957a). The constant flow of Waikoropupu Springs is important for the flora and fauna which are never affected by the floods or periods of low flow that often occur in streams and rivers.

New Zealand cold springs studied

Water discharge for various cold springs in New Zealand is given in Table 1.1. Discharge has been converted into m^3/s if originally stated in other units. Waikoropupu Springs, Hamurana Springs and Otangeroa Springs have the highest discharges of cold springs in New Zealand. Waikoropupu Springs may be termed a first order spring (Meinzer 1927) whereas Hamurana Springs and Otangeroa Springs are second order springs. The others included in the Table and also the 12 cold springs recorded in the Auckland region (Petty 1972) are third order springs.

Large cold springs in general

Water discharge rates for large cold springs in various countries are compared in Table 1.3. (The Source de Vaucluse in Southern France was not included in the Table as it was considered to be a resurgence rather than a spring). Waikoropupu Springs rank as one of the largest known cold springs in the world, along with Silver Springs, Florida; Rainbow Springs, Florida and Big Spring, Missouri. Waikoropupu Springs are the only first order springs in New Zealand whereas there are at least 65 springs of this order in the United States (Meinzer 1927).

TABLE 1.3: Water discharge of large cold springs in various countries.

Spring and location	Discharge (m^3/s)	Reference
Rainbow Springs, Florida, U.S.A.	20 (av.)	Ferguson *et al* (1947)
Silver Springs, Florida, U.S.A. - main boil - total flow	9.5 (av.) 19 (av.)	Odum (1957a)
Big Spring, Missouri, U.S.A.	12 (av.)	Meinzer (1927)
Waikoropupu Springs, Takaka, N.Z.	about 11 (av.)	Water and Soil Divn., Ministry of Works, Nelson (pers. comm.)
Springs at Paderborn, Westfalen, Germany	8.8 (max.)	Stille (1903) *cited by* Berg (1951)
Many English Springs	0.105-0.158	Walters (1936) *cited by* Berg (1951)
Lille Blaakilde, Jutland, Denmark	0.105-0.146	Berg (1951)
Krystallkallen, Karlsbad, Sweden	about 0.06 (av.)	*in* Berg (1951)

MORPHOMETRY

Mapping methods

The shoreline of the Main Spring and Dancing Sands was surveyed with a theodolite and metal surveying tape, using 17 marker points (Fig. 1.3). The study area at the Springs was restricted to the area upstream from lines joining points 1 to C and C to 14 (Fig. 1.3) since this included the deep basins of the Main Spring and the Dancing Sands.

Self Contained Underwater Breathing Apparatus (SCUBA), supplemented by snorkel-diving, was used in much of the present study. Underwater mapping was carried out by divers who recorded

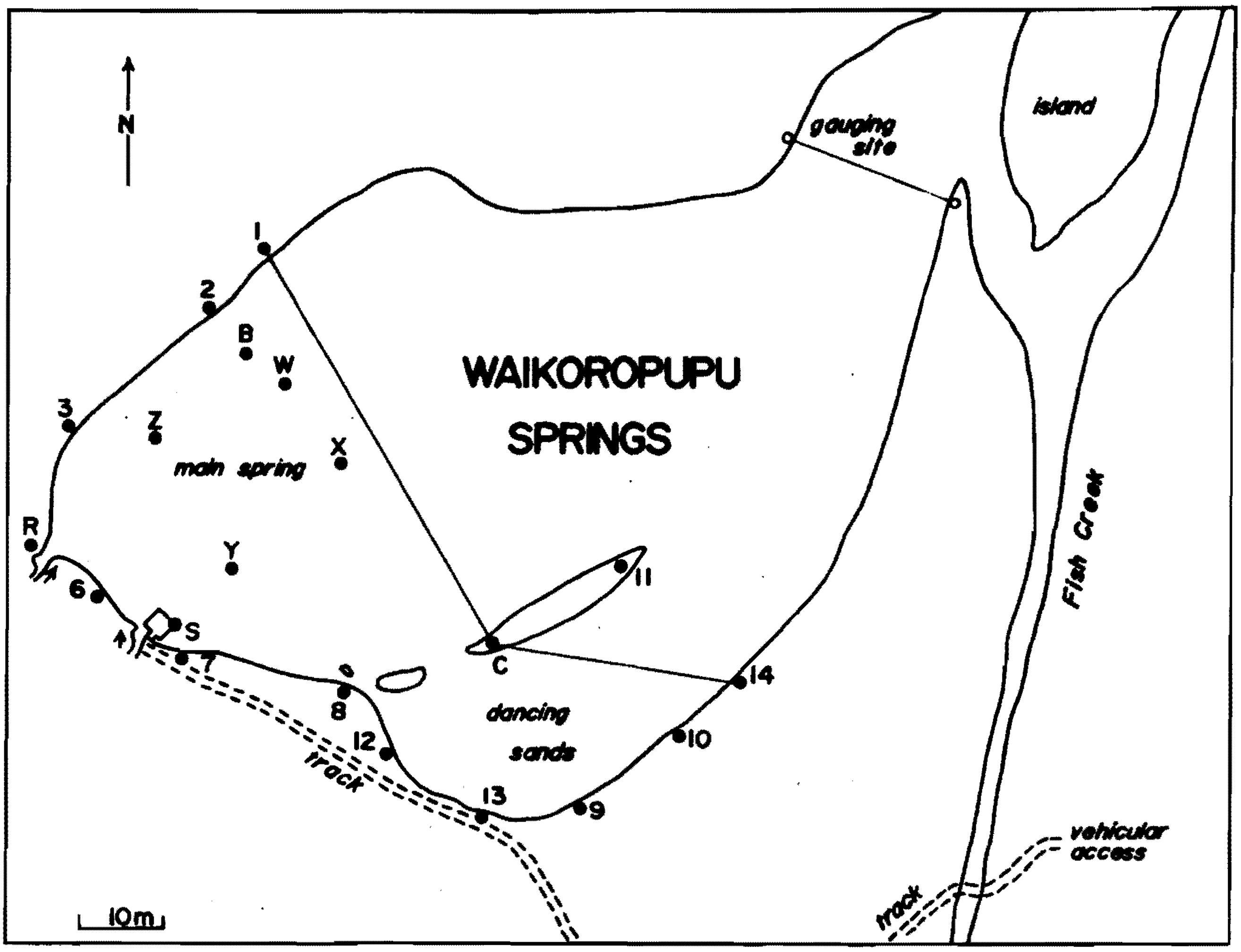


FIG. 1.3: Map of Waikoropupu Springs showing shoreline markers (1-14, C, R, S) and underwater markers (B, S, W, X, Y, Z). (Based on Department of Lands and Survey records).

observations on painted fibro boards or Permatrace using a 3B lead pencil. A glass bottomed viewing box clamped to an aluminium dinghy was used for additional observations to reduce the time spent diving in the cold water. Visibility to the bottom of the Springs was good. Six underwater marker points (Fig. 1.3) were used, and distances between pairs of points were measured using nylon ropes marked at 0.5 m intervals. Water depths were measured at 2 m intervals along nine transects between marker points. With all transect ropes in place, sketch maps of the Main Spring and the Dancing Sands were made from direct underwater observation. Substrate types and positions of water vents were noted. A contour map of the Springs was constructed from these sketch maps and depth measurements. Since the water level at the Main Spring fluctuated by only 9 cm between October 1970 and May 1971, it was not necessary to correct for depth measurements made on different days. Area (by the weight method) and volume were calculated as outlined by Welch (1948).

Results

Morphometric data for Waikoropupu Springs are summarised in Table 1.4.

TABLE 1.4: Morphometric data for Waikoropupu Springs.

Altitude	about 14 m above sea level	
Area (total)	1791 m^2	
Volume (total)	2523 m^3	
	Main Spring	Dancing Sands
Area	1341 m^2	450 m^2
Maximum depth	6.9 m	2.7 m
Diameter	49 m	22 m
Volume	2166 m^3	357 m^3

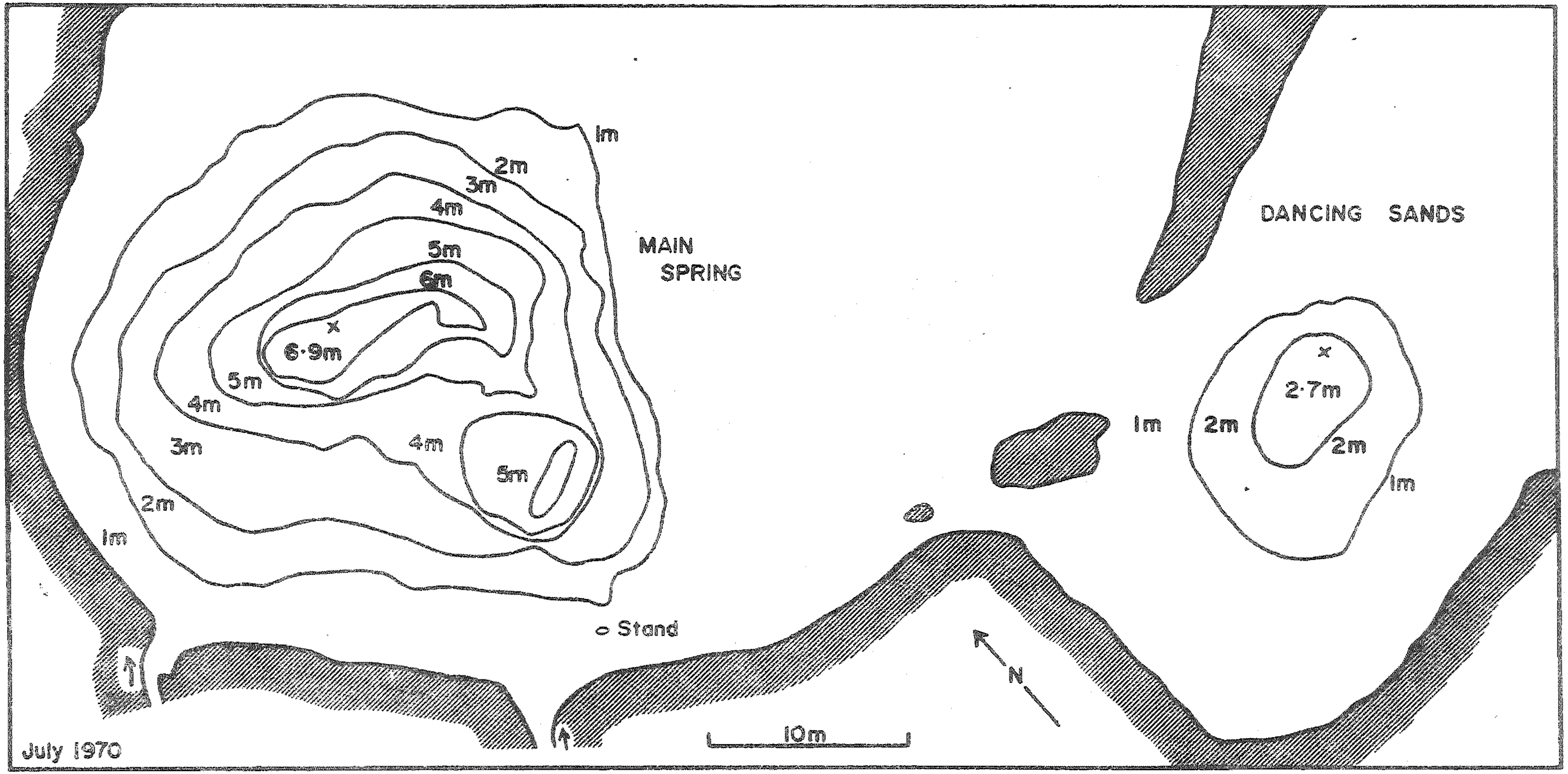


FIG. 1.4: Bathymetric map of Waikoropupu Springs. Depth contours are at one metre intervals.

The basin of the Main Spring is circular in outline (Fig. 1.4) with a diameter of 49 m. After heavy rain two streams enter at the surface. Contours at depths less than 4 m reflect the circular shape but contours at greater depths show that there are two depressions in the Main Spring. Maximum depth of the Main Spring is 6.9 m. The Main Spring is separated from the Dancing Sands by a large area of shallow water and two islands. The basin of the Dancing Sands is circular with a diameter of 22 m and has a maximum depth of 2.7 m. Immediately downstream from both springs, the outflow is less than 1 m deep. The area of the Main Spring is three times that of the Dancing Sands and the volume of the Main Spring six times that of the Dancing Sands.

The mean holding time for water in the Springs (i.e. volume of the Springs/rate of water discharge) was calculated as only 3.8 minutes.

SUBSTRATE

The major substrate types in the Springs are bedrock, boulders, gravel and sand, according to a modification of Wentworth's classification (Welch 1948). The bedrock of the Main Spring basin (Fig. 1.5) has been eroded in the deeper areas and substantial boulder banks have developed between the "principal" vent (Fig. 1.6) and the other vents, around the Main Spring basin and downstream from the Main Spring and the Dancing Sands (i.e. the spring outflow). These boulders have diameters greater than 12 cm. Quaternary gravels of diameter 2-8 mm, that originally overlay the bedrock, fill the deepest parts of both the Main Spring basin and the Dancing Sands. Sand (diameter 0.25-0.125 mm) with occasional stones (diameter 0.8-6 cm) occurs in some parts of the Main Spring and the

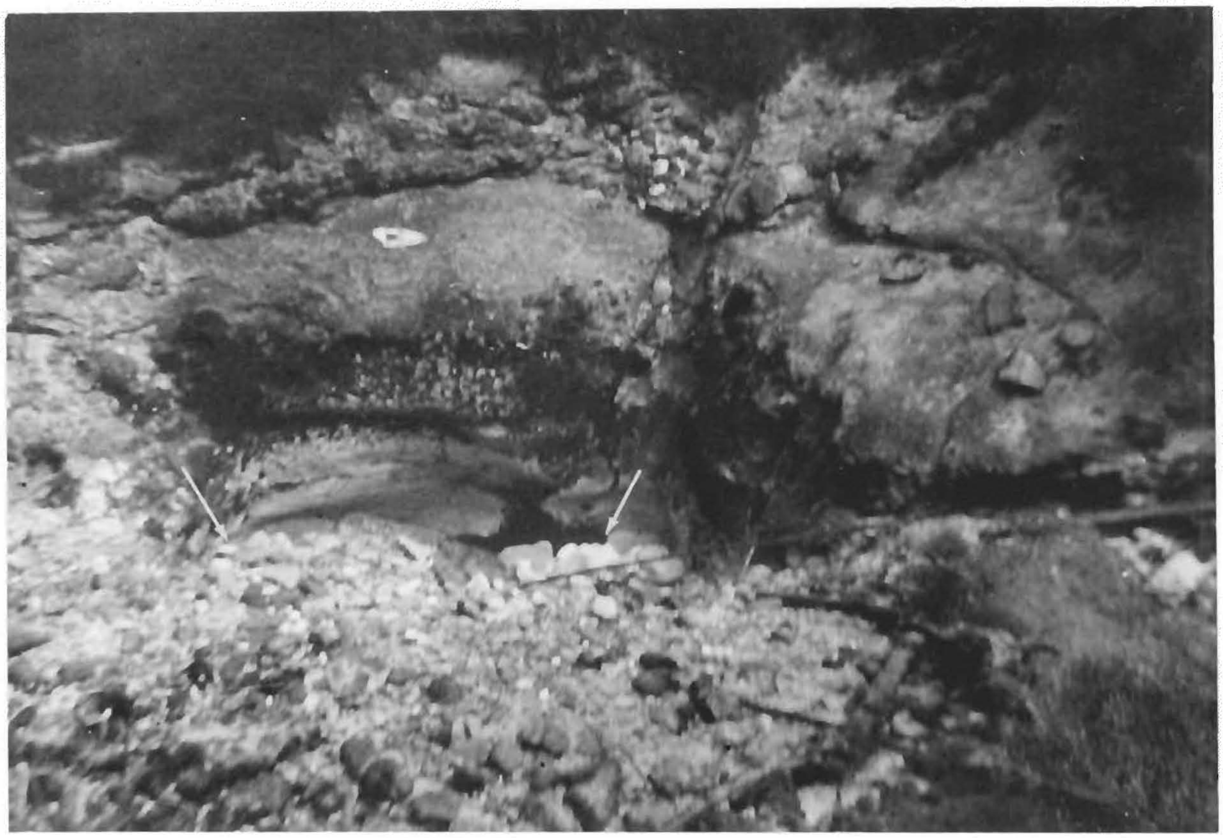


PLATE 1.2: "Principal" vent, Main Spring. Water issues through a vent in the bedrock 4.6 m underwater and 1.5 m wide. (Arrows mark the extremities of the vent). Dark areas on the bedrock are growths of algae and bryophytes. Photo: G.C. Wells

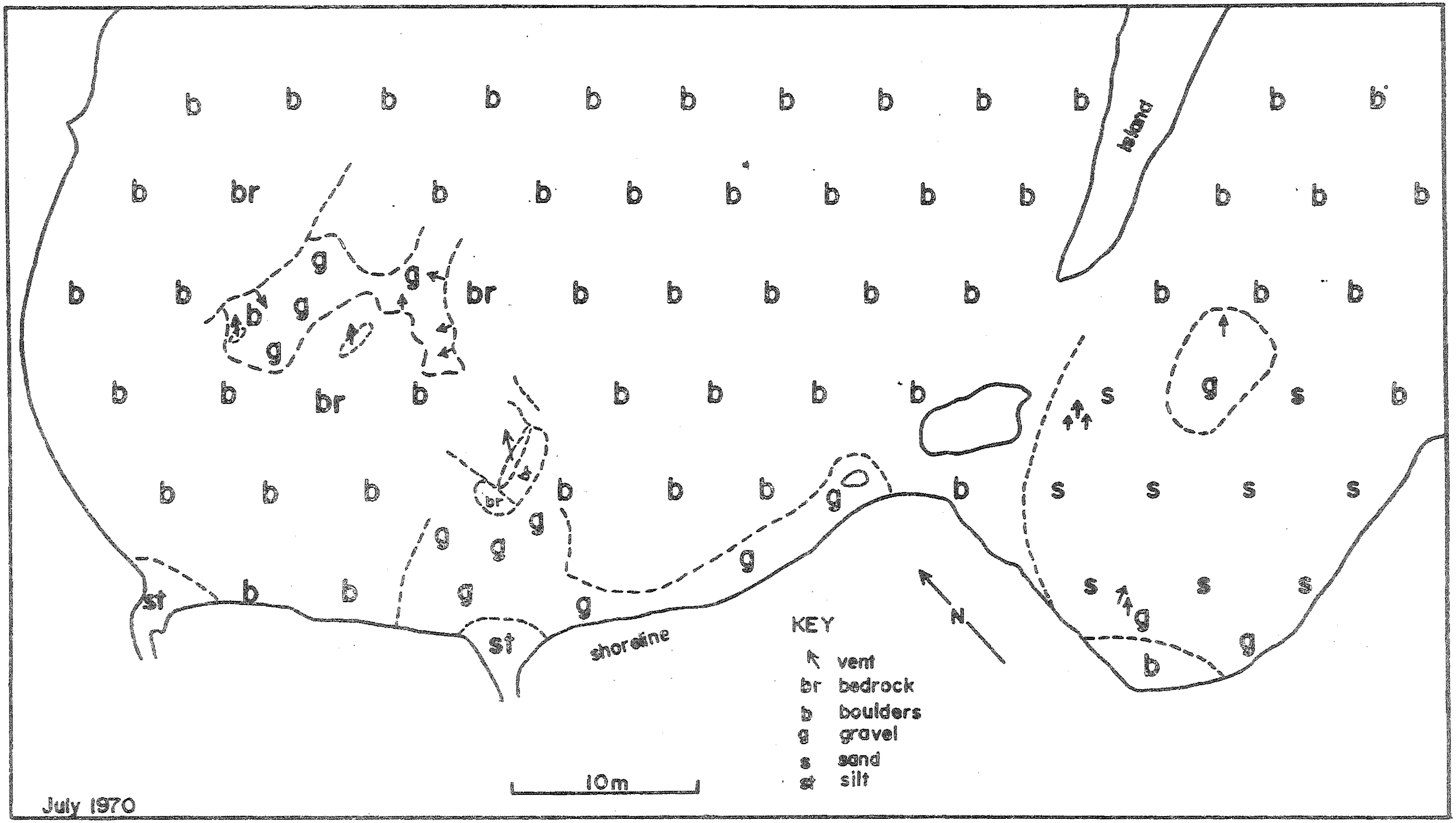


FIG. 1.5: Map of Waikoropupu Springs showing main substrate types and major water vents. Dotted lines indicate boundaries between substrate types. Arrows indicate direction of water flow from vents.

shallower areas of the Dancing Sands but silt (diameter less than 0.06 mm) occurs only around the stream inlets in the Main Spring. In some areas, such as the gravel vents of the Dancing Sands, the substrate is unstable. Much of the substrate is covered by aquatic vegetation.

WATER VENTS

The Main Spring discharges through eight major water vents in carbonaceous gritty sandstone (Fig. 1.6) but the relative discharges of these vents are not known. The "principal" vent (Plate 1.2) is an opening 1.5 m wide through bedrock at depth 4.6 m. The discharge is oblique and causes a slight dome at the surface of the water (Plate 1.1). This vent cannot be entered by divers as the force of the water is sufficient to carry men and also boulders to the surface. Water from the other large vents issues horizontally from under cliffs at depths of between 4 m and 5 m. These vents are barely visible at the surface of the water. The Dancing Sands discharge through numerous vents in the gravel at depths between 0.5 m and 2.7 m.

WATER VELOCITY

Water velocity was measured 10 cm above the substrate in various parts of the Springs using a Gurley current meter No. 622-F and an underwater compass. As Fig. 1.6 was compiled from field work on both 19 September and 3 October 1970, velocities were standardised by reference to water discharge data, assuming that water velocity was proportional to water discharge. No attempt was made to measure water velocity in mid-water nor in the vicinity of weed beds.

Water velocity at one large horizontal vent was 110 cm/s. Velocities measured in water between 1 m and 2 m deep

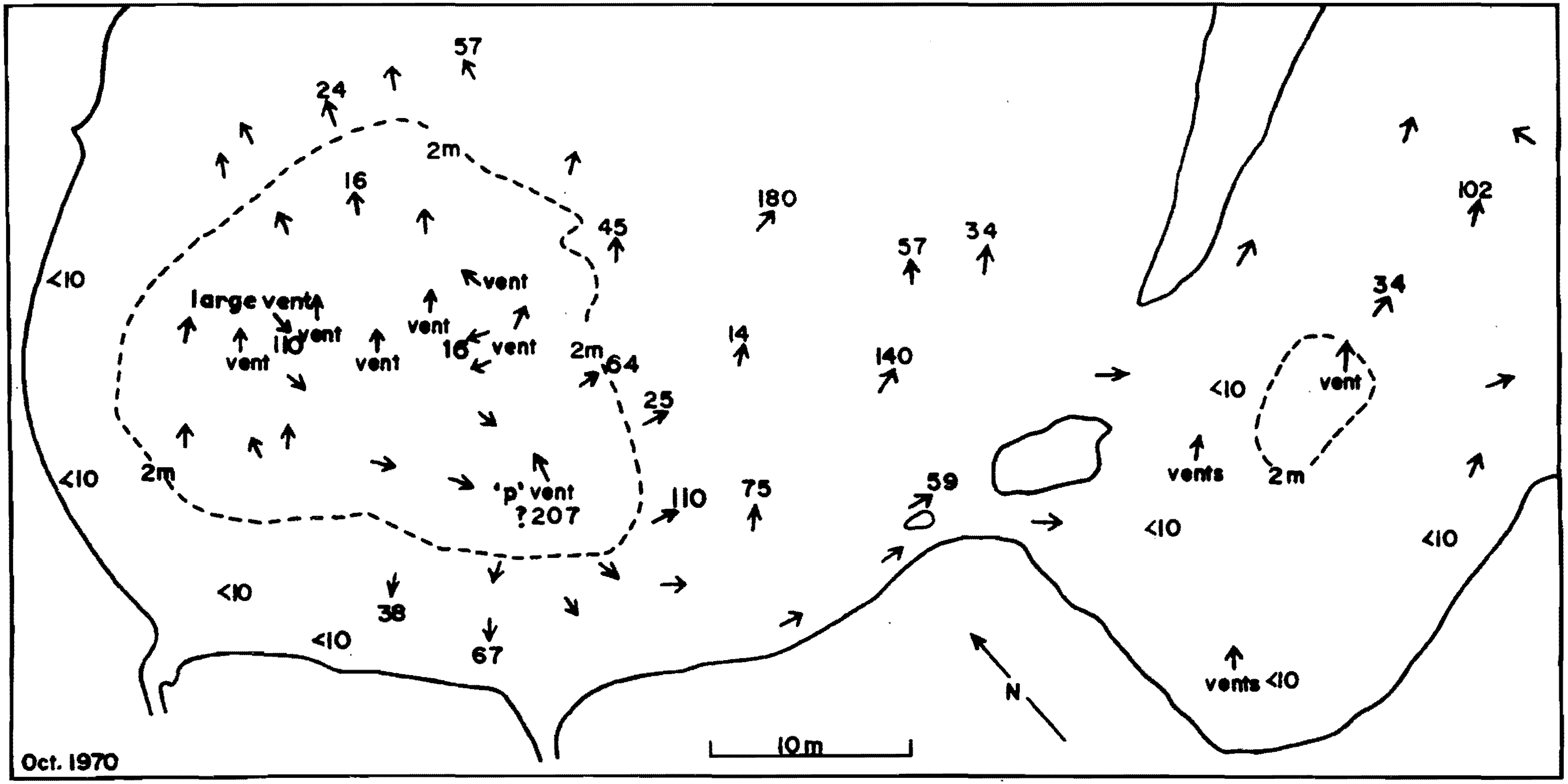


FIG. 1.6: Map of Waikoropupu Springs showing velocity of water currents. All readings were taken 10 cm above the substrate and are expressed in cm/s, corresponding to a water discharge rate of approximately 15 m^3/s. "P" indicates "principal" vent.

ranged from 25 cm/s to 57 cm/s i.e. moderate to strong (Berg 1943), whereas readings in very shallow water were often as high as 100 cm/s i.e. very strong. Generally the shoreline was characterised by water velocities less than 10 cm/s i.e. very slight. In a number of places the direction of the water flow, but not its speed, was measured. In the deeper areas of the Main Spring, the direction of water flow 10 cm above the substrate was frequently different from the direction of the flow at the surface.

In Waikoropupu Springs, substrate type and water velocity were broadly related, as has been observed elsewhere by Nielsen (1950c) and Schmitz (1961), but some substrate types were found in a wide range of water velocities and, for this reason, both substrate type and water velocity are used in the present study. Generally, bedrock and boulders were found in moderate to very strong velocities; gravel in slight to strong velocities and silt in a very slight velocity.

LIGHT

The light transmission properties of the water in Waikoropupu Springs were measured to quantify its remarkable clarity. Some seasonal changes in the light climate were investigated.

Methods

Light intensity in the air at Waikoropupu Springs at noon on cloudless days in mid-summer and mid-winter was measured by taking three readings using a TRILUX foot candle meter (P. GOSSEN & Co.). Monthly mean total radiation for Takaka (langleys/day) was estimated from De Lisle (1966).

To measure light penetration in Waikoropupu Springs, a light-dependent-resistor (LDR) with optical centre of gravity

680 nm and waveband width 400-900 nm was used. The LDR was housed in a waterproof metallic container with a glass front. The container was mounted on a short horizontal boom and attached to one end of a 12 m long, graduated cable. The other end of the cable was connected to a micro-ammeter. The LDR was calibrated against a TRILUX meter by technical staff of the Zoology Department, University of Canterbury. A gelatine neutral density filter of 1% attenuation (KODAK) was seated between two pieces of glass and used as required to reduce the light intensity reaching the photocell to less than 10,000 lux. A set of filters from Chance Pilkington (OR_2, OG_1, OB_{10} and OX_7) could be used in combination with the LDR, but no opal glass or Plexiglas disc was available for use with the filters.

Measurements at Waikoropupu Springs were made at about noon on cloudless days from a rubber dinghy moored above the deepest part of the Springs. The method followed was that of Vollenweider (1969). The LDR was used without coloured filters in mid-winter 1971 and both with and without coloured filters in mid-summer 1971. Generally three sets of readings were made with each colour filter. Light intensity values at depths from 0.1 m to 6.9 m were plotted on semi-logarithmic paper and extrapolated to zero depth. Taking the zero depth value as 100% all values were recalculated as percentages and re-plotted. The optical properties of the water were derived in two ways:

1. The transmission coefficient T_k^{λ} was calculated using the formula:

$$T_k^{\lambda}\% = \frac{i_2}{i_1} \times 100 \text{ where } \begin{array}{l} i_1 = \text{intensity at depth } z_1 \\ i_2 = \text{intensity at depth } z_2 \\ \text{and } z_2 - z_1 = 1 \text{ m} \end{array}$$

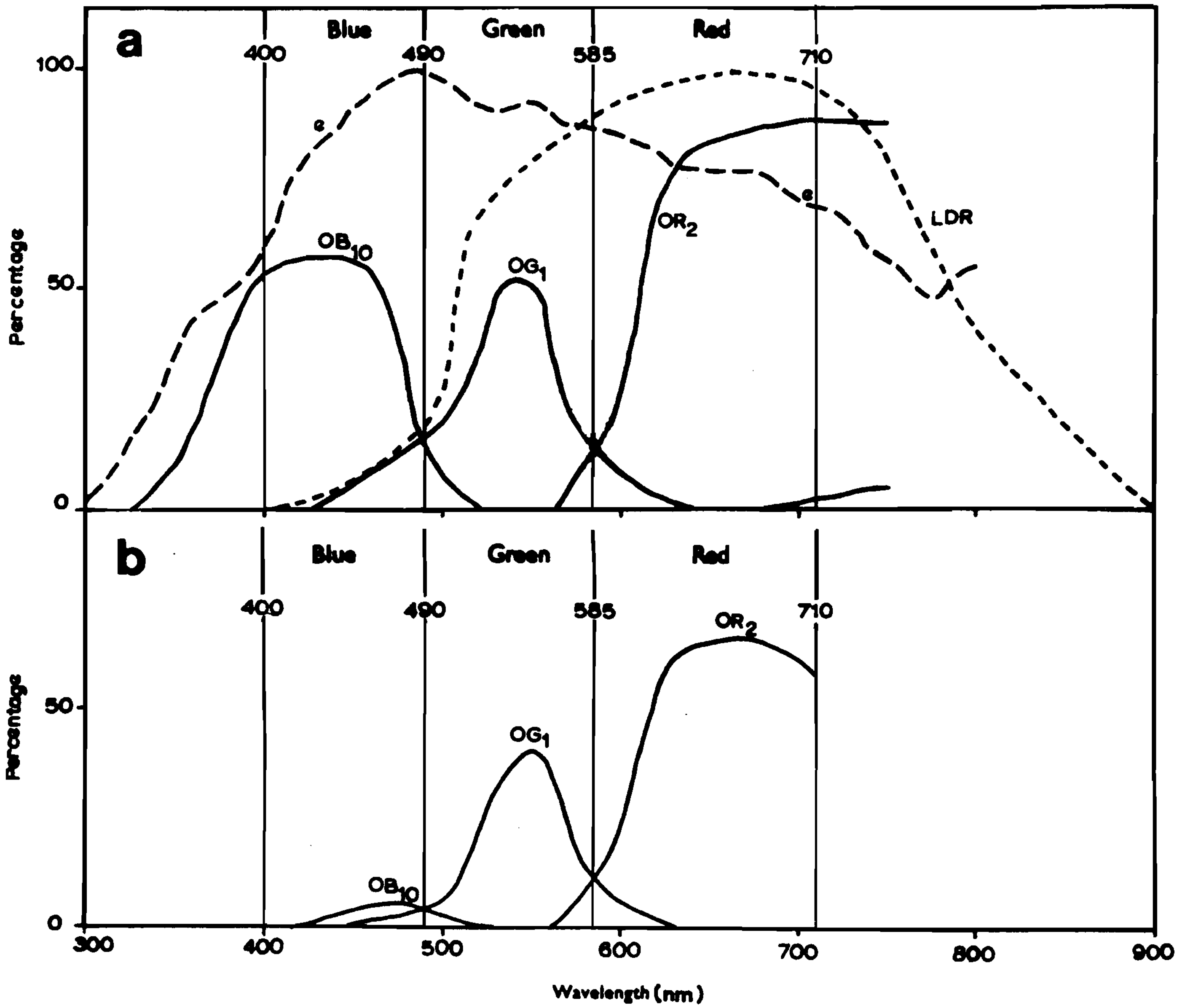


FIG. 1.7: Spectral response curves for a light dependent resistor (LDR).
a. Basic data for calculation of response of the LDR. LDR indicates relative response curve for a light dependent resistor (data from manufacturer); OB_{10}, OG_1, OR_2 indicate percentage transmission of colour filters (data from manufacturer); e indicates relative energy distribution of radiation from sun and sky (Taylor and Kerr 1941). Vertical bars define wavelength bands corresponding to each filter.
b. Relative response of the LDR with various filters and sun and sky as energy source. Vertical bars define wavelength bands corresponding to each filter.

This coefficient was corrected to 100% zenith sun and 0% sky energy, following Whitney (1938). The correction permits direct comparison of transmission coefficients measured at any latitude and with any amount of cloud cover.

2. The vertical extinction coefficient $E_v^{\prime\lambda}$ was calculated to base 10:

$$E_v^{\prime\lambda} = \frac{1}{Z_2 - Z_1} (\log i_1 - \log i_2)$$

No correction was made for the "shifting effect" of the water column above the mounted photocell (Sauberer 1962).

Transmission curves for the filters (except OX_7) and a sensitivity curve for the LDR were obtained from the respective manufacturers (Fig. 1.7a). Transmission through the front window was assumed to be non-selective (Westlake 1965) and was ignored. Following Vollenweider (1961), the spectral sensitivity curve of each filter in combination with the LDR was calculated for an equal energy spectrum. The spectral energy distribution of sunlight was obtained from Taylor and Kerr (1941) and was recalculated as a percentage of the maximum energy (Fig. 1.7a).

The relative response of the LDR with various colour filters and the sun and sky as energy source could then be calculated (Fig. 1.7b). The large amount of overlap between the responses with blue and green filters was undesirable, but could only have been avoided by using different filters or a selenium photocell which would show a greater relative response in the blue waveband than does the LDR. Using Fig. 1.7b, wavelengths were selected to subdivide the photosynthetic range: 400-490 nm (blue filter); 490-585 nm (green filter) and 585-710 nm (red filter). It was assumed that percentage transmission determined for each filter applied to all radiant energy in that waveband.

Calculation of the light climate at various depths in Waikoropupu Springs at noon in mid-winter and mid-summer was carried out according to Westlake (1966). The proportions of total radiant energy in each waveband in air were estimated by planimetry from Fig. 1.7a and the same proportions were assumed for radiant energy just below the water surface. In fact, energy losses due to surface reflection of direct radiation are a function of wavelength, but differences between energy losses of wavelengths within the photosynthetic range are so small (McLellan 1965) that they can be ignored. Using the transmission coefficient of light in each waveband, it was possible to calculate the percentage of radiant energy remaining in each of the three wavebands at any depth as a percentage of the total radiant energy at that depth in mid-summer.

Since the correction factor for immersing the photometer (Westlake 1965) was not known, the surface reflection loss was obtained from Sverdrup, Johnson and Fleming (1942). (This assumed that the surface reflection loss from the rippling surface of Waikoropupu Springs was the same as that from a smooth water surface). The total radiant energy at any depth could then be compared not only with the total radiant energy just below the water surface, but with the total radiant energy in air. As absolute values for total radiant energy in air at Waikoropupu Springs were not available, relative values were calculated, based on light intensity measurements at the Springs at noon in mid-winter and mid-summer.

Results and Discussion

Total radiation is higher in Takaka than in most other areas in New Zealand. Monthly mean total radiation for Takaka in June (mid-winter) is 160 langleys/day and for December (mid-summer) is 550 langleys/day (De Lisle 1966) so that total radiation in air is 3.4 times higher on an average day in mid-summer than in mid-winter. The light intensity in air at noon on a cloudless day in mid-winter was 31,000 lux and in mid-summer was 82,000 lux; i.e. 3.8 times higher in mid-summer.

Penetration data for light at all wavelengths in Waikoropupu Springs are summarised in Table 1.5.

TABLE 1.5: Light penetration in Waikoropupu Springs, as determined by a light dependent resistor with optical centre of gravity about 680 nm.

Date	Time (hours)	Weather conditions	Vertical attenuation coefficient (E_v log base 10)	Transmission coefficient
28 Jun 1971	1030	cloud	0.12	77%
28 Jun 1971	1230	bright sun	0.06	87%
4 Jan 1972	1215	bright sun	0.10	80%
4 Jan 1972	1300	bright sun	0.09	80%

Values of the vertical extinction coefficient (E'_v) varied from 0.06-0.12 (using $\log_{10}$), corresponding to values for E_v of 0.14-0.28 (using ln). The transmission coefficient varied from 77-87% and, corrected for zenith sun and zero sky energy, varied from 81-90%. Some variation in values for these coefficients would be expected because of the changing light environment due to the rippling water surface (Odum 1957a). The extinction coefficient recorded in Waikoropupu Springs is similar to that of 0.06 for Silver Springs and 0.08 for Wakulla Springs, Florida (Odum 1957a). These values for springs are comparable with those for the clearest ocean water (0.06, Sverdrup _et al_ 1942) and are much lower than those generally reported for rivers (Westlake 1966).

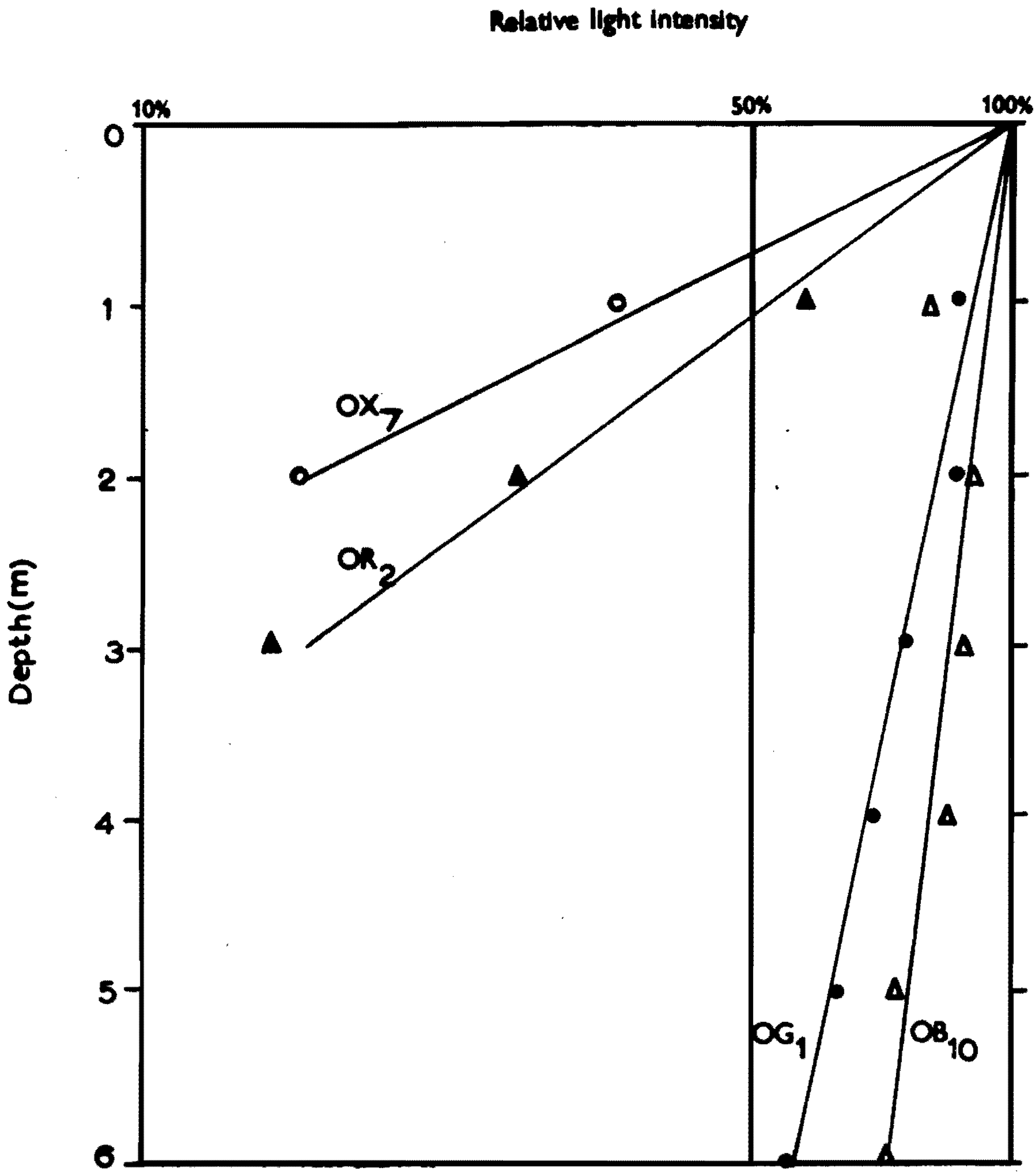


FIG. 1.8: Light penetration in Waikoropupu Springs. Semi-logarithmic plot of the relative light intensity measured at various depths at noon in mid-summer. Open circles denote measurements made with filter OX_7, closed circles denote filter OG_1, open triangles denote filter OB_{10} and closed triangles denote filter OR_2.

The penetration of light of different wavelengths at noon in mid-summer 1971 at Waikoropupu Springs is shown in Fig. 1.8. Blue and green light, as measured by filters OB_{10} and OG_1, had transmission coefficients of 95% and 91% respectively. Red and violet light, as measured by filters OR_2 and OX_7, were quickly absorbed by the water and had transmission coefficients of only 54% and 39% respectively.

The areas of the circles in Fig. 1.9 represent the relative total radiant energy available for photosynthesis at a given depth in the Springs at noon on a cloudless day in mid-summer and in mid-winter. There is slightly more total energy present at a depth of 6 m in mid-summer than there is in air in mid-winter. At noon, in mid-summer, total radiant energy at 6 m is 40% of that in air and in mid-winter is 33% of that in air. The ratio of total radiant energy at noon in mid-summer to noon in mid-winter rises from 2.7 in air to 3.0 at 1 m, 3.1 at 3 m and 3.2 at 6 m.

Because of the spectral sensitivity of the water, the proportion of radiant energy in each waveband varies with depth (Fig. 1.9 - indicated by sectors of circles). In air, blue, green and red wavebands (as already defined) contain 29%, 34% and 37% respectively of the total photosynthetic energy. At 6 m, at noon in mid-summer, the proportions have altered to 51%, 47% and 2% respectively.

There appear to be no detailed studies of seasonal changes in total radiation at different depths in running water. Schmitz (1960), in a comprehensive investigation, measured light energy to very low levels, in various wavebands at different depths in the River Danube and its tributaries but measurements were made only in autumn. Westlake (1966)

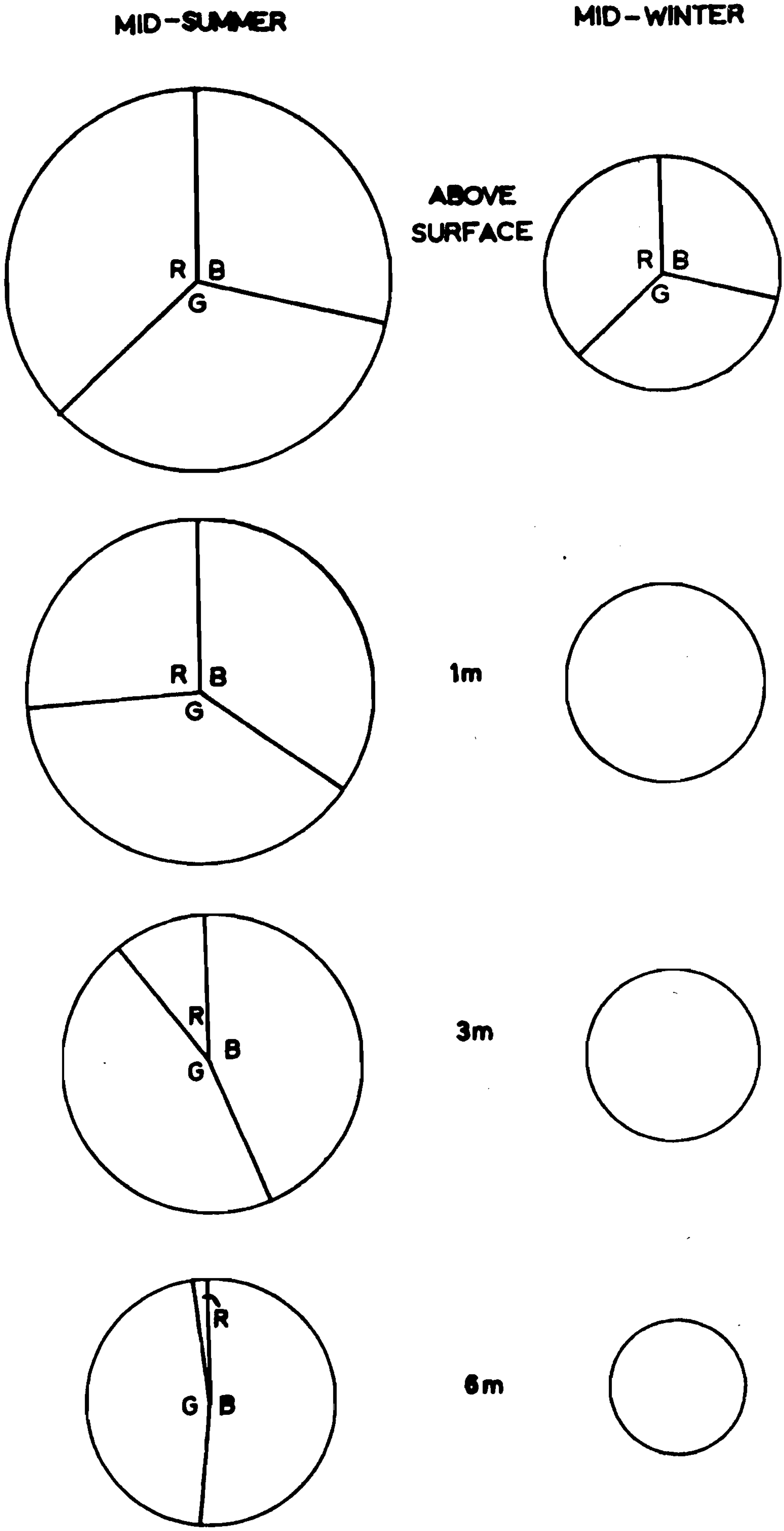


FIG. 1.9: The light climate at various depths in Waikoropupu Springs at noon in mid-summer and mid-winter. Total photosynthetic energy is represented by the area of each circle and distribution of this energy between red, green and blue wavebands is represented by sectors of each circle (see text).

reviewed studies on the light climate for plants in rivers but did not present data on seasonal changes in the light climate other than changes resulting from shading by trees.

B. CHEMICAL FEATURES

DISSOLVED OXYGEN

Waikoropupu Springs

Methods

Four-weekly determinations of dissolved oxygen were made from July 1970 to September 1971. Water samples from the Main Spring and Dancing Sands were collected using a 500 ml separating funnel by diving directly in front of the vents. Samples were transferred from the separating funnel into a 300 ml oxygen bottle, fixed in the field and transported in polystyrene boxes containing portable cooling pads to Nelson for analysis by a modified Winkler method (Rideal and Stewart 1901). Oxygen-saturation values were obtained from Welch (1948).

Results

The levels of dissolved oxygen in Waikoropupu Springs are recorded in Table 1.6 (and Appendix 2) and were found to be fairly constant at the "principal" vent of the Main Spring (58-64% saturation) and at the Dancing Sands vent (54-65% saturation). Dissolved oxygen was also measured at various points in the Springs on 3 October 1970 at 1400 hr. Values obtained were 6.7 g/m^3 ("principal" vent - Fig. 1.6), 6.8 g/m^3 (large horizontal vent - Fig. 1.6), 6.8 g/m^3 (X - Fig. 1.3), 7.0 g/m^3 (near C - Fig. 1.3) and 7.2 g/m^3 (at gauging site 110 m downstream from the "principal" vent - Fig. 1.3). Thus, percentage saturation rose from 60% at the "principal" vent to 65% at the confluence of the Springs outflow and Fish Creek.

New Zealand cold springs studied

No data are available for Three Springs, Otangeroa Spring or the Spring at Lake Hayes. In none of the cold springs studied was the water fully saturated with dissolved oxygen; the level of dissolved oxygen was 29% saturation at Western Springs and 79% at Hamurana Springs (Table 1.7).

Cold springs in general

Water from cold springs in other countries is also low in dissolved oxygen e.g. 28-60% saturation, Silver Springs, Florida, U.S.A. (Odum 1957a); 26-65% saturation, Root Spring, Massachusetts, U.S.A. (Teal 1957); 21% saturation, Spring of Igarapé do José, Amazon Basin (Sioli 1954). Neilsen (1950a) observed that spring water is typically low in dissolved oxygen and that the level of dissolved oxygen is reduced from saturation values by biological and chemical oxidations as the spring water percolates underground.

OTHER CHEMICAL ANALYSES

Waikoropupu Springs

Methods

Samples were collected as described above and were transferred to glass or plastic bottles for transport to Nelson. Analysis (by Dr. M. E. U. Taylor) was begun about three hours after collection of the sample. Phenolphthalein acidity, total alkalinity and free carbon dioxide were determined as outlined by the American Public Health Association (APHA) (1965). Ammoniacal nitrogen was estimated directly by the method of Solorzano (1970 unpublished), as was total oxidisable nitrogen (following distillation by the method of the APHA 1965). Nitrate- and nitrite-nitrogen, "available" phosphorus and silicate were estimated by the methods of Strickland and Parsons (1968); chloride and sulphate by methods modified from the handbook of Tintometer Ltd. (1967); iron by a method adapted from Feigl (1958) and boron by the method of Malyuga (1970). Calcium, magnesium, sodium and potassium were estimated by emission flame spectrophotometry. Following methods outlined by the APHA (1965), an anion-cation balance was calculated. The results of this calculation suggested that the water analysis was complete.

The level of hardness was determined from Taylor (1958) and the concentration of calcium was referred to the scale of Ohle (1934) modified by Williams (1964).

Results and Discussion

The results of three water analyses for the Main Spring and for the Dancing Sands, carried out between January 1970 and May 1971, are summarised in Table 1.6 and details are given in Appendix 3. Results of three additional partial analyses for major anions and cations in the Main Spring and two for the Dancing Sands are also included in Appendix 3.

Water from Waikoropupu Springs is clear, of almost neutral pH, and tastes slightly salty. A high specific conductance indicates a high level of dissolved salts. The water may be classed as moderately hard and rich in calcium.

The specific conductance of ground water from Waikoropupu Springs was higher than that recorded for most surrounding surface waters and chemical analyses available for cold springs in other countries indicate that this is often the case (Ferguson *et al* 1947). Cimbrian spring water is rich in nutritive salts (Nielsen 1950a) and Lander Springbrook, New

Mexico discharges water that is highly mineralised (Noel 1954). The level of dissolved solids in Silver Springs, Florida (Odum 1957a) is nearly as great as that in Waikoropupu Springs. These high specific conductances can be attributed to the length of time the spring waters are underground in contact with containing beds.

Some differences between the Main Spring and the Dancing Sands were noted (Table 1.6). The Dancing Sands consistently had a lower specific conductivity than the Main Spring (533 μS/cm and 650 μS/cm respectively) and all the major cations and anions except nitrate nitrogen were at lower concentrations in the Dancing Sands than in the Main Spring. It has been found that adjacent boils a few ~~yards~~ metres apart may or may not have a similar chemical composition (Ferguson et al 1947), and Odum (1953) cited the example of Chassahowitzka Springs where boils about ~~a few~~ one hundred ~~feet~~ metres apart had chlorinities of 50 ppm (g/m^3) and 730 ppm (g/m^3).

The level of nitrate nitrogen in the water from Waikoropupu Springs (0.3 g/m^3) was slightly higher than the mean level in ground waters used as drinking water supplies in New Zealand (0.1 g/m^3 ; Kingsford, Hogan, Robertson and Sutcliffe 1970) but much lower than that in ground water in the Waikato area (0.2-59 mg/ℓ (g/m^3); Baber and Wilson 1972). Further work is required in the Nelson/Takaka area before the nitrate nitrogen level in Waikoropupu Springs can be compared with that of either ground waters or surface waters in the region. Levels of nitrite nitrogen, ammoniacal nitrogen and total oxidisable nitrogen in the Springs are low, as is the level of "available" phosphorus. The level of silicate is low compared to that in two of the other cold springs studied

TABLE 1.6: Chemical analysis of water from the Main Spring and the Dancing Sands, Waikoropupu Springs. The mean value and range of values are mostly based on three full analyses made between January 1970 and May 1971 by M.E.U. Taylor (Appendix 3); values for dissolved oxygen are based on 17-20 analyses made from 26 Jan 1970 to 26 Sep 1971 by the author (Appendix 2). A dash denotes data not available.

	Main Spring	Dancing Sands
pH	7.5 (7.4-7.6)	7.5 (7.4-7.7)
Odour	none	none
Taste	mineral	mineral
Colour (A.P.H.A.)	clear	clear
Turbidity (Silica scale)	none	none
Specific conductance (μS/cm) 25°C	650 (580-759)	533 (494-592)
	(g/m^3)	(g/m^3)
Acidity, phenolpthalein	10.6 (7.6-13.0)	8.1 (6.0-10.0)
Total alkalinity	163 (157-167)	153 (147-158)
Total dissolved solids 180°C	374 (354-394)	307 (298-316)
Total fixed solids 500°C	349 (326-372)	280 (274-285)
Free CO_2	5.8 (4.9-6.7)	4.5 (3.7-5.3)
O_2 diss.	6.6 (6.4-7.0)	6.7 (6.0-7.1)
NO_3 -N	0.31 (0.29-0.33)	0.32 (0.28-0.34)
NO_2 -N	$\leqslant$0.001	<0.001
NH_4 -N	0.041(0.004-0.069)	0.027(<0.001-0.060)
Total oxidisable nitrogen	$\leqslant$0.10	$\leqslant$0.10
'Available' P	0.001	<0.005
Cl	102 (90-115)	68 (56-80)
SO_4 -S	57 (54-59)	44 (36-51)
SiO_2 - Si	2.3 (2.2-2.5)	2.3 (2.2-2.5)
Ca	64 (60-72)	58 (52-64)
Mg	8.5 (6.8-9.4)	6.9 (6.0-7.8)
Na	63 (50-72)	48 (39-54)
K	5.4 (5.3-5.5)	4.3 (3.7-4.4)
Fe	0.02	0.1 (nil-0.2)
B	0.5	-

(Table 1.7).

Levels of free carbon dioxide are moderately high in the Main Spring (5.8 g/m^3) compared to atmospheric equilibrium (0.65 g/m^3, Hutchinson 1957). Ruttner (1963) stated that the carbon dioxide content of spring water is often several times greater than the level corresponding to atmospheric equilibrium.

The unusually high concentrations of Na^+, K^+, Mg^{2+}, Cl^- and SO_4^{2-} in Waikoropupu Springs are quite unlike the concentrations of these ions in surface waters in the Takaka district. This high salt content is not due to salts dissolved in rain water since rivers in the Nelson-Takaka area have sodium chloride concentrations of about 3-8 g/m^3 compared to 165 g/m^3 at the Main Spring, Waikoropupu Springs (M.E.U. Taylor, pers. comm.). Neither is it due to seawater intrusion as the ratios of $Na^+ : Ca^{2+}$ and $Ca^{2+} : Mg^{2+}$ (0.98 and 7.5 respectively) are quite unlike those encountered in sea water (26.3 and 0.32 respectively) (Harvey 1957). Rather, the high concentration of the salts suggests that the Springs water derives from salt laden strata in the containing beds (Odum 1953).

The boron content of ground water is an indication of its origin: a level of 0.5 g/m^3 (Waikoropupu Springs) confirms an older Pleistocene cold aquifer (Schofield 1960).

New Zealand cold springs studied

All the cold springs listed in Table 1.7 discharge clear water of nearly neutral pH. No water analysis is available for Otangeroa Spring. Total dissolved salts vary from 374 g/m^3 (Waikoropupu Springs) to 50 g/m^3 (Three Springs), reflecting the different origins of the springs. The spring waters fall into three groups:

(a) those flowing from volcanic areas, characterised by a high level of silicate (Western Springs and Hamurana Springs)

(b) those flowing from marble or limestone, characterised by a high level of calcium (Waikoropupu Springs, Spring at Lake Hayes)

(c) those flowing directly from rivers, characterised by a low level of dissolved salts (Three Springs).

The Spring at Lake Hayes discharges slightly hard water rich in calcium and flows from soft incoherent limestone or calcareous tuf (Wood 1962). This was formed by moss and fresh-water algae precipitating carbonate of lime from the waters of Lake Hayes, at a higher post-glacial lake level (Park 1909). Water from this spring differs from that of Waikoropupu Springs principally in having much lower levels of ions such as sodium, potassium and chloride and hence a much lower level of total dissolved solids.

Water from Hamurana Springs has a high level of silicate reflecting the origin of the spring in the Taupo Volcanic Zone (Healy, Schofield and Thompson 1964). The water is soft and very poor in calcium with levels of magnesium, sodium, potassium and chloride that are much lower than those at Waikoropupu Springs. Nitrate nitrogen is present at about the same level as in Waikoropupu Springs. The level of available phosphorus is moderately high compared to that in the other cold springs and water from the spring provides a considerable input of phosphorus to Lake Rotorua (Fish 1969).

Water from Western Springs has a high level of silicate and flows from the Auckland Volcanic Zone (Schofield 1967). The water is probably soft and is poor in calcium. Dissolved phosphate is moderately high. There appears to have been a steady enrichment of the water since the earliest chemical

TABLE 1.7: Chemical analysis of water from Waikoropupu Springs and four other cold springs in New Zealand. A dash denotes data not available.

	Main Spring, Waikoropupu Springs, Takaka	Spring at Lake Hayes, Queenstown	Hamurana Springs, Rotorua	Western Springs, Auckland	Three Springs, Fairlie
pH	7.5	7.1	-	7.1-7.4	6.6
specific conductance (μS/cm) 25°C	650	196	79	251	-
	(g/m^3)	(g/m^3)	(g/m^3)	(g/m^3)	(g/m^3)
Total dissolved solids 180°C	374	105	94	164	50
Total fixed solids 500°C	349	93	83	136	-
Free CO_2	5.8	-	-	-	10
O_2 diss.	6.6	-	8.8	2.9	-
O_2 (% satn)	60%	-	79%	29%	-
NO_3 -N	0.31	1.26	0.23	0.7	nil
NO_2 -N	$\leqslant$0.001	nil	<0.001	trace	nil
NH_4 -N	0.04	nil	0.004	$\leqslant$0.04	nil
'Available' P	0.001	0.001	0.079	0.023	-
Cl	102	1.5	5.4	20	4
SO_4 -S	57	-	-	-	-
SiO_2 -Si	2.3	-	19	10-25	-
Ca	64	35	2.3	11.7	-*
Mg	8.5	3.5	1.4	-	-*
Na	63	4.2	8.3	23	-
K	5.4	1.1	2.2	5.0	-
Fe	0.02	-	<0.1	$\leqslant$0.1	nil
					* Total hardness 20
Reference	M.E.U. Taylor (pers. comm.) (Appendix 3) Present study O_2 diss.	S.F. Mitchell and C.W. Burns (pers. comm.) M.E.U. Taylor (pers. comm.) Sample collected 21 Feb 1971 Mg Ca T.D.S. T.F.S.	Fish (1969) NO_3 -N NH_4 -N 'Avail' P M.E.U. Taylor (pers. comm.) Sample collected 3 May 1971	Johnstone (1972) pH O_2 diss. NO_3 -N NO_2 -N NH_4 -N 'Avail' P SiO_2 - Si M.E.U. Taylor (pers. comm.) Sample collected 30 Mar 1971	Drummond and Hogan (1965, p.16) D. J. Hogan (pers. comm.) Free CO_2

analysis in 1916. Nitrate nitrogen seems to have increased from a level of about 0.3 ppm (0.3 g/m^3) (1916) to 0.4 ppm (0.4 g/m^3) (1924), 0.6 ppm (0.6 g/m^3) (1936) (Dominion Laboratory Annual Reports) and 0.7 (0.7 g/m^3) (Johnstone 1972). This may be the result of an increase in domestic and industrial wastes in the catchment area due to urbanisation. Water from the springs was first used as a drinking water supply for Auckland in 1887 but by 1920 it was used as an emergency supply and then only after chlorination (Petty 1972).

Three Springs discharge through a small area of Tertiary limestone (Gair 1967) and provide the town supply for Fairlie. The source of the spring water is the nearby Opihi River and rainfall on the limestone terrain (Oborn 1963 unpublished). The chemical composition of the water is similar to that in rivers flowing nearby, being soft and low in chloride. The remainder of the chemical analysis reported in Table 1.7 is not adequate for discussion.

Many spring waters have been termed mineralised, using rather arbitrary criteria such as palatability, and there is no comprehensive classification of the chemistry of spring waters. Whitford (1956) recognised four types of mineralised spring water and two types of fresh spring water in Florida. However, Petty's (1972) investigation of springs in the Auckland region of New Zealand showed that Whitford's classification was too restrictive.

Following the recommendation of the International Biological Programme, the present study adopted freshwaters as those with a level of total dissolved solids (T.D.S.) less than 300 g/m^3. Waters with a level of T.D.S. appreciably above this value were termed mineral, as opposed to salt, when their ionic composition differed from that of sea-water (Peterken 1967). On this basis, all the New Zealand cold springs studied discharge freshwater, with the possible exception of Waikoropupu Springs (T.D.S. - 374 g/m^3) which could be recognised as mineralised and oligohaline (chlorides about 100 and up to 600 g/m^3; Whitford 1956) on the basis of their chloride content. While their algal communities (see Part 2) suggest hard fresh-water, the fauna (see Part 3) shows some response to the increased chlorinity. Generally, the flora and fauna of Waikoropupu Springs were similar to those of the other New Zealand cold springs studied and since these were termed freshwater, Waikoropupu Springs was also (from a biological viewpoint) termed a freshwater spring.

CONCLUSION

The water temperature of Waikoropupu Springs is constant all year round and water chemistry and discharge (and hence velocity) are reasonably stable with time, so that light is the major seasonal variable in the Springs. Largely because of the short time that water is held in the Springs, water temperature and chemistry are essentially uniform throughout the study area. The major variables within the study area are then substrate, water velocity and depth.

The physical and chemical features of cold springs are further considered in the General Discussion where methods of classification of cold springs are discussed.

PART 2.

VEGETATION

INTRODUCTION

There have been few studies made of the ecology of aquatic plants in the running waters of New Zealand, and studies of the flora of cold springs are limited to a limnological survey of Western Springs, Auckland (Johnstone 1972), based on a Masterate thesis on the control of Salvinia sp. in the Springs (Johnstone 1969 unpublished). Marshall (1973) included a list of the aquatic plants found during his faunal survey of the Avonhead Springs, Christchurch.

There has been a limited amount of work on the flora of cold springs in other countries. Whitford (1956) described the algae of Silver Springs, Florida, U.S.A. and Yount (1956) studied algal productivity in the same springs. In the United Kingdom, Round (1960) listed the diatoms in 22 small cold springs in Yorkshire and Eaton (1967 unpublished, cited by Round 1968) studied the diatoms in cold springs near Bristol. Morton (1942a,b; 1944) recorded the species of moss and higher plants in about twenty springs in Hallstatt, Germany and Pennak (1953) noted that watercress is commonly found in springs in the United States. There have been few other studies specifically on the flora of cold springs but records of cold spring flora are contained in papers by Odum (1957a,b), Teal (1957), Minckley (1963) and Tilly (1968) in the United States; Demel (1923) in Poland; Kühn (1940) in Austria, and Nielsen (1942) and Thorup (1966) in Denmark.

Water temperature and chemistry are important in determining the global distribution of plants in running waters, but their local distribution depends on such factors as water velocity, the physical nature of the substrate and irradiance (Westlake 1973). However the irradiance factor was largely ignored in the present study because of the high level of light energy available at all depths in Waikoropupu Springs. In torrential and swiftly flowing waters, a substrate of rock or unstable boulders restricts the flora, in temperate latitudes, to algae, lichens and bryophytes whereas a lower water velocity and a finer substrate of gravel and sand permit submerged angiosperm communities to become established. A substrate of silt allows the development of emergent and heterophyllous angiosperms (Sculthorpe 1967). In the present study, the relationship between distribution of plant species, substrate type and water velocity in Waikoropupu Springs was examined.

METHODS

PRESERVATION OF SPECIMENS

At the six cold spring studied (Fig. GI.1), collections of bryophytes and angiosperms for identification were made by hand while wading in shallow water or while SCUBA diving in the deeper water of Waikoropupu and Hamurana Springs. Specimens were placed into numbered plastic bags (15 x 15 cm) and transferred to the laboratory in polystyrene boxes containing cooling pads. No appreciable decay in plants was observed over periods of up to 48 hours.

At Waikoropupu Springs, epipelic and epilithic algae were removed from their substrates with forceps and were placed in plastic bags while underwater. Epiphytic algae were scraped from plants in the laboratory using forceps and a scalpel. Algae were preserved in either Lugol's Iodine (Chlorophyta) or 3% formalin.

For the preservation of the natural colours of Chlorophyta, moss protonema and spores of fungi and ferns, Johansen (1940) used glycerol (=glycerine) and Dr. M.E.U.

Taylor suggested its use in the present study for preserving aquatic bryophytes and angiosperms. The following method was developed and proved highly successful: specimens were washed in distilled water, shaken dry and completely submerged in 50% glycerol (v/v aqueous) in glass jars of volume ranging from 10 to 250 ml. After three days, the specimens were transferred to 100% glycerol in similar jars. After a further week, specimens could be removed from glycerol and dried between absorbent paper for preservation in an herbarium.

WAIKOROPUPU SPRINGS

VEGETATION MAP

In Waikoropupu Springs, the areas of all plant species except Nasturtium microphyllum were constant enough over the period January 1970 to January 1972 to allow a vegetation map to be compiled from field work carried out on several dates: 4 Apr 1970, 28 Jul 1970, 5 Dec 1970 and 29 Oct 1971.

Three mapping methods were used: (a) Direct underwater observation. In the deeper areas of the Main Spring, distribution of vegetation was drawn onto contour maps while the observer was underwater. (b) Measurement along transect ropes. Maps of the Springs, showing the position of seven transect ropes with their 0.5 m markings, were drafted onto underwater writing boards. A diver worked along each transect rope, either wading or swimming, holding a 2 m graduated measuring pole at right angles to the rope and sketching vegetation boundaries directly onto these maps. An area of only 250 m^2 could be mapped in one day's diving time (i.e. one hour) because of the low water temperature and strong current. (c) Photographs of emergent watercress beds. Every four weeks, transect ropes were laid out on the surface between points S and 3, 6 and 2,

TABLE 2.1: Substrate, water depth, water velocity and major species of plants at sampling sites located as shown in Fig. 2.1.

Site 1	boulders, 0.6 m, moderate velocity *Cratoneuropsis relaxa*, *Fissidens rigidulus*, *Spirogyra* sp.
2	bedrock, 4.3 m, slight velocity *Cratoneuropsis relaxa*
3	vertical concrete, 0.3 m, moderate velocity *Cratoneuropsis relaxa*, *Fissidens rigidulus*
4	boulders, 0.6 m, strong velocity *Lophocolea austrigena*, *Lophocolea minor*, *Neesioscyphus phoenicorhizus*, *Cyathophorum bulbosum*
5	gravel, 0.5 m, strong velocity *Juncus microcephalus*, *Synedra ulna* (summer only), *Achnanthes* sp. (summer only)
6	gravel, 2.5 m, strong velocity *Myriophyllum elatinoides*, *Synedra ulna* (summer only), *Achnanthes* sp. (summer only)
7	silt and water, less than 0.8 m, very slight velocity *Nasturtium microphyllum*, *Lemna minor*
8	gravel, 2.5 m, slight velocity *Nasturtium microphyllum*
9	gravel, 6.5 m, moderate velocity *Nasturtium microphyllum*
10	boulders, 0.5 m, very strong velocity *Entophysalis rivularis*, *Hildenbrandia rivularis*

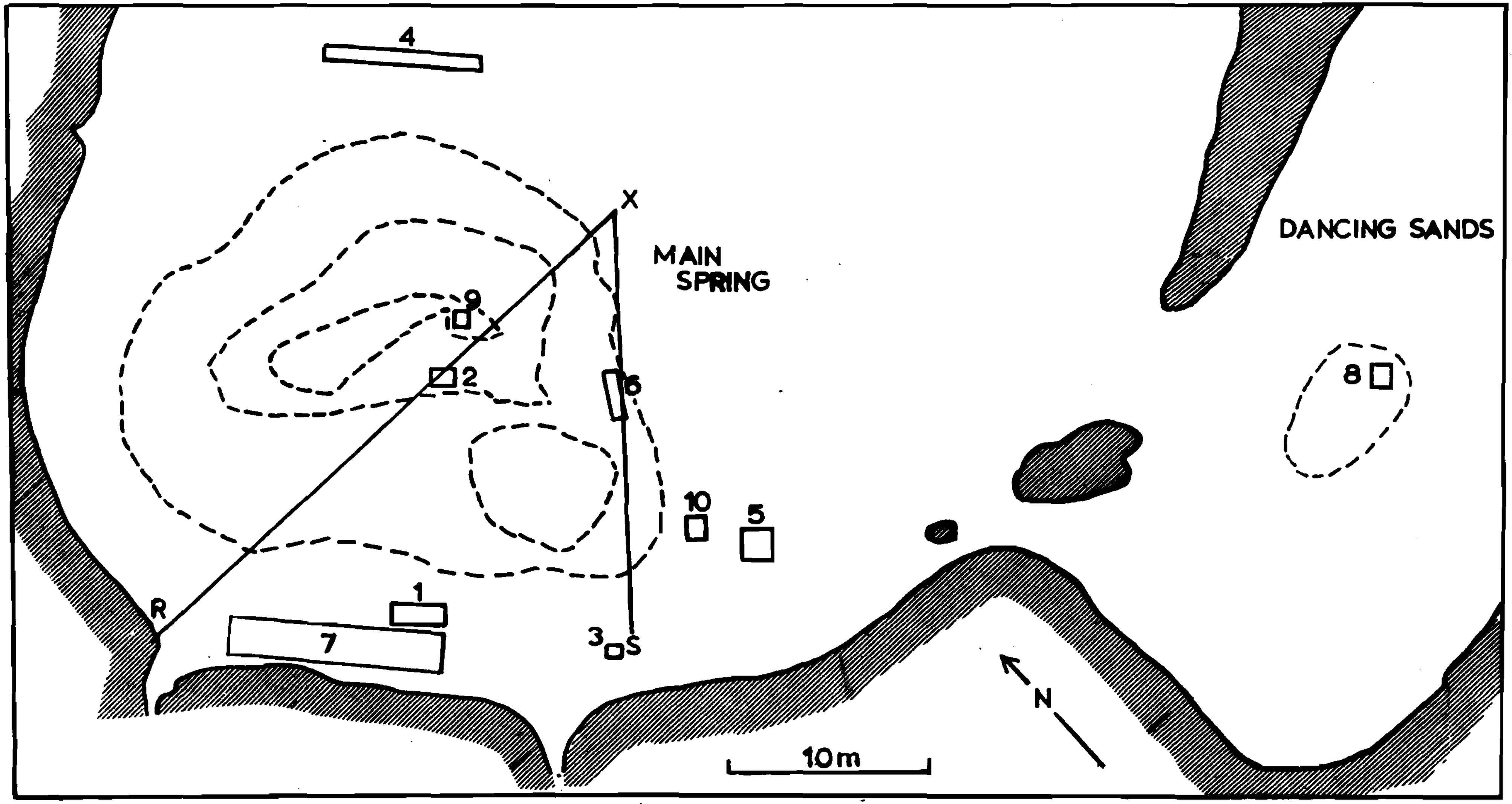


FIG. 2.1: Map of Waikoropupu Springs showing regular sampling sites, details of which are given in Table 2.1. Depth contours at 2 m intervals are indicated by dotted lines. Lines joining X and R and X and S indicate representative transects (Fig. 2.4).

and C and 14 (Fig. 1.3). Black and white photographs were taken from fixed points on the ground and from the top of the stand S (height 2 m). Using the photographs and additional measurements from the transect ropes, maps of the watercress beds were drawn and the area covered by the beds was measured by planimetry.

The final vegetation map was drawn on translucent paper and was superimposed on a contour map of the Springs, so that maximum depth and depth distribution of each plant species could be determined. The area covered by each plant species in the Main Spring and Dancing Sands was measured by planimetry.

Notes on vertical distribution, substrate type and growth form of plants (Sculthorpe 1967) were recorded by an underwater observer.

Sites for the regular sampling of plants and animals, shown in Fig. 2.1, were selected away from boundaries of plant species. These sampling sites represented four major substrate and water velocity types: boulders in a very strong water velocity, boulders in a moderate to strong water velocity, gravel in a slight to strong water velocity and silt in water of slight velocity. A fifth substrate and water velocity type, unstable sand and gravel in a slight to strong water velocity was not a regular sampling site. Details of sampling sites are recorded in Table 2.1.

COLLECTION OF SAMPLES

Bacteria and fungi

To estimate numbers of bacteria and fungi in the inflowing water, duplicate samples of water from the "principal" vent of the Main Spring were collected into sterile, screw-top glass jars and taken to the laboratory in polystyrene boxes (see below), where a sample of 1 ml was plated in OXOID plate count agar. To estimate the numbers on plants, a sample of moss (Cratoneuropsis relaxa) at site 1 and of watercress (Nasturtium microphyllum) at site 7 was collected underwater into a sterile jar. In the laboratory, the plant sample (about 50 g wet wt) was shaken thoroughly in the jar to remove any adherent animals. The sample was then removed from the jar and again shaken. Duplicate sub-samples (10 g wet wt) were weighed in sterile bottles containing 90 ml of phosphate buffer (K_2HPO_4, 20 g/ℓ) and glass beads. The sub-samples were shaken and ten-fold dilutions prepared in the same diluent. Duplicate 1 ml samples of appropriate dilutions were plated in OXOID plate count agar. Plates were incubated at $10^{o}C \pm 1C^{o}$ for 14 days and then counted. Duplicate sub-samples (10 g wet wt) of plant were dried as described below to obtain dry weight. Samples were collected every four weeks from 19 September 1970 (plants) or from 6 December 1970 (water) until 24 October 1971.

Algae, bryophytes and angiosperms

Several methods were used for quantitative sampling of algae, bryophytes and angiosperms depending on the substrate on which the plants were growing. Jointly-occurring species of bryophytes were sampled together.

1. Small samples of bryophytes on a substrate of bedrock or boulders were taken using a cylindrical cork borer (area 3.5 cm^2) as described by Douglas (1958) except that no ramrod was used for removal of the sample from the borer. The borer was pressed onto the substrate and the sample was removed from the substrate using a steel diving knife. Above water, forceps were used to transfer the sample from the cork borer into a small plastic container.

(a) Cratoneuropsis relaxa and Fissidens rigidulus

Estimates of biomass of these mosses were made from quadruplicate samples taken at site 1 where C. relaxa and F. rigidulus occurred together, and from duplicate samples at site 2 where C. relaxa occurred alone. To determine seasonal changes in biomass of the jointly-occurring species, sampling was carried out on the vertical concrete pillar at site 3. Every four weeks from 4 October 1970 to 19 February 1972 six samples of the mosses were collected from the pillar at a depth of 0.3 m. No area was sampled twice. The mean dry weight of moss per unit area was calculated for each sampling date.

(b) Lophocolea spp., Neesioscyphus phoenicorhizus and Cyathophorum bulbosum

A total of ten samples was taken on two days at site 4 where boulders were covered in these three bryophytes and quadruplicate samples were taken from boulders at depth 4.3 m where Lophocolea spp. occurred alone.

2. Larger samples of bryophytes on a substrate of boulders were taken by removing boulders from the Springs. A Wisconsin trap (Welch 1948) with mesh of aperture size 0.42 mm, was placed downstream from, and just touching, the boulder to be sampled, which was then placed in the trap by a SCUBA diver. In the laboratory, bryophytes were removed from the boulder and the boulder's length, breadth and height were measured. The boulder area, i.e. the standard area of Ulfstrand (1968), was calculated by multiplying boulder length by breadth, and was used in all subsequent computations as the area of the boulder sample. This was generally about 250 cm^2. The ratio of standard area: height was determined as a measure of the shape of the boulder.

This method used to sample bryophytes was considered an improvement on the methods of Frost (1942), Hynes (1961) and Minckley (1963) since it collected animals from beneath boulders and at the edge of the bryophyte cover. Unfortunately it could only be used when the substrate was suitable.

Spirogyra sp.

Approximate values for the biomass of this alga at site 1 were obtained from samples of boulders covered in the moss, Cratoneuropsis relaxa, on which this alga was epiphytic. One sample was taken every four weeks from October 1970 to February 1972 using a Wisconsin trap.

3. Most large samples of submerged and emergent angiosperms were taken by SCUBA diving using a Wisconsin trap (Welch 1948). The open bag was placed over the plant sample and a steel diving knife was used to trim round the outside of the sampler, and to remove plants when the substrate was bedrock. A substrate of sand or gravel was collected with the sample in an attempt to include most of the roots. The area of such samples was that of the Wisconsin trap (0.09 m^2).

(a) Juncus microcephalus - rush

Measurements of biomass per unit area were made about every three months at Site 5 using one sample collected with a Wisconsin trap.

(b) Myriophyllum elatinoides - water milfoil

Samples were taken at site 6 in the manner described for J. microcephalus.

4. Floating angiosperms were sampled with a modified Hess sampler (Hess 1941). The sampler used was 20 x 20 x 45 cm long, the area of the opening being 0.04 m^2. The bottom of the sampler was covered with metal screening of aperture size

0.42 mm. The sampler was introduced beneath floating vegetation and the sample cut away from the surrounding vegetation with a knife.

(a) Nasturtium microphyllum - watercress (floating and emergent)

Most of the watercress sampled at site 7 was floating but some was loosely attached to the substrate in water less than 80 cm deep (Fig. 2.4b). Preliminary sampling of N. microphyllum at site 7 was carried out on 19 September 1970 by collecting five samples. Three samples were found to be sufficient to estimate the mean biomass with a 5% chance that the error in the true mean biomass would exceed 5 g/sample (i.e. about 10% of the sample biomass) (Sokal and Rohlf 1969). Therefore, to determine seasonal changes in biomass per unit area, three samples were taken every four weeks from site 7 using a Hess sampler to include all root material. The location sampled each day was chosen by random numbers with non-replacement. Additional samples were taken from the Dancing Sands on 28 November 1971 to determine biomass per unit area.

(b) Lemna minor - duckweed

Twelve measurements of biomass per unit area were made over the period 10 January 1971 to 19 February 1972, using L. minor obtained from the samples of watercress.

In the field, plants were placed from the sampler into heavy duty plastic bags using water from a wash bottle to rinse out the sampler. Polystyrene boxes containing portable cooling pads were used to transport the samples to the laboratory where they could be stored at 4°C for up to 36 hours without noticeable deterioration.

SORTING OF PLANT SAMPLES

Plant samples were washed free of animals using tap water flowing through a series of sieves. (Animals were retained as described in Part 3). For drying, each species of plant was placed in a separate aluminium tray, except for jointly-occurring bryophytes which were dried together. Samples of angiosperms (except *Lemna minor*) were divided into shoots and roots.

DRY WEIGHT AND ORGANIC MATTER

Plants were dried to constant weight at 105°C for 16 hours and were weighed to 0.1 g on a top pan balance within 30 seconds of removal from the oven. Duplicate sub-samples (about 5 g) from at least two samples were ashed at 550°C for 90 minutes, cooled in a desiccator and reweighed. Organic matter was calculated as dry weight of plant minus ash content.

PRODUCTIVITY OF FREE-FLOATING *NASTURTIUM MICROPHYLLUM*

An estimate of the production of floating plants can be derived from periodic measurements of their biomass. However, a special problem arises when floating beds of plants change in area as well as in biomass per unit area. The present study adopted the method of Westlake (1969) in determining the production per unit area as the total production divided by the mean bed area, i.e. the mean of the bed areas at the beginning and end of the sampling period.

Cattle grazing at the Springs from time to time severely depleted the watercress beds. Sampling periods for production measurements were restricted to times when cattle were excluded from the Springs.

The total biomass of the watercress beds for each

PLATE 2.1(overleaf): "Wai Koro Pupu" about 1904. (From the Tyree Collection, Alexander Turnbull Library, Wellington, N.Z. Ref.: 695).

sampling date was obtained from the product of the mean of the sampled biomass per unit area and the area of the beds. The change in biomass of the beds between subsequent sampling dates was then obtained by subtraction. The change in total biomass was divided by the mean bed area to give the production per unit area for the sampling period.

Productivity was obtained by dividing production per unit area by the number of days in the sampling period and this value was converted to g organic matter/ m^2.day.

RESULTS

WAIKOROPUPU SPRINGS

A. TERRESTRIAL VEGETATION

EARLY MODIFICATION

Remnant stands of forest suggest that the Waikoropupu Valley was originally covered by a forest of podocarps, including rimu (Dacrydium cupressinum) and totara (Podocarpus totara), and hardwoods including beech (Nothofagus spp.). This cover was removed by logging of podocarps, clear-felling and burning prior to the earliest photographic record of the Springs (about 1904). Gold-mining in the area between the Springs and Fish Creek about 1900 resulted in mine tailings still visible today. By about 1904, manuka (Leptospermum scoparium) and/or kanuka (L. ericoides) had colonised the area around both Springs (Plate 2.1). An extensive growth of the fern Blechnum capense developed between the Main Spring and the Dancing Sands. The native monocotyledons, New Zealand flax (Phormium tenax) and cabbage tree (Cordyline australis) were present. A native rush, Juncus section Genuini (? J. gregiflorus) (det. E. Edgar), can be seen in an early photograph of the Springs outflow just below the Dancing Sands but is no longer present.

THE PRESENT VEGETATION

The main species of terrestrial plants found today at the Springs and alongside the outflow are listed in Table 2.2. The native species listed are found throughout New Zealand in lowland habitats (Allan 1961; Poole and Adams 1964; Moore and Edgar 1970). Many of them are typical of forest e.g. *Cyathodes* spp., *Phymatodes diversifolium* and *Blechnum capense*, or swamp e.g. *Cordyline australis*, *Phormium tenax*. Others form scrub (*Leptospermum* spp.).

The distribution of the major vegetation types (forest, scrub and grass) is shown in Fig. 2.2. Native podocarp-hardwood forest has regenerated, forming a dense cover on the island between the Main Spring and the Dancing Sands and to the east of both the Dancing Sands and the Springs outflow. Shading of the Springs by trees is negligible except near the island between the Springs, and very little leaf litter enters the Springs.

Manuka and kanuka, gorse (*Ulex europaeus*) and Scotch broom (*Cytisus scoparius*) form scrub areas around the Main Spring and Dancing Sands and along the west side of the outflow. The scrub reaches a height of 8 m. Flax and cabbage trees are still present around the shoreline, but are not common.

Some of the shoreline of the Main Spring and Dancing Sands has been converted to grass for access and recreation. Between the grass and the Main Spring grow numerous introduced plants (e.g. water forget-me-not, *Myosotis caespitosa*). A large area to the west of the Main Spring and outflow has been converted to pasture on which dairy cattle are grazed. From time to time these cattle have access to the entire Springs area.

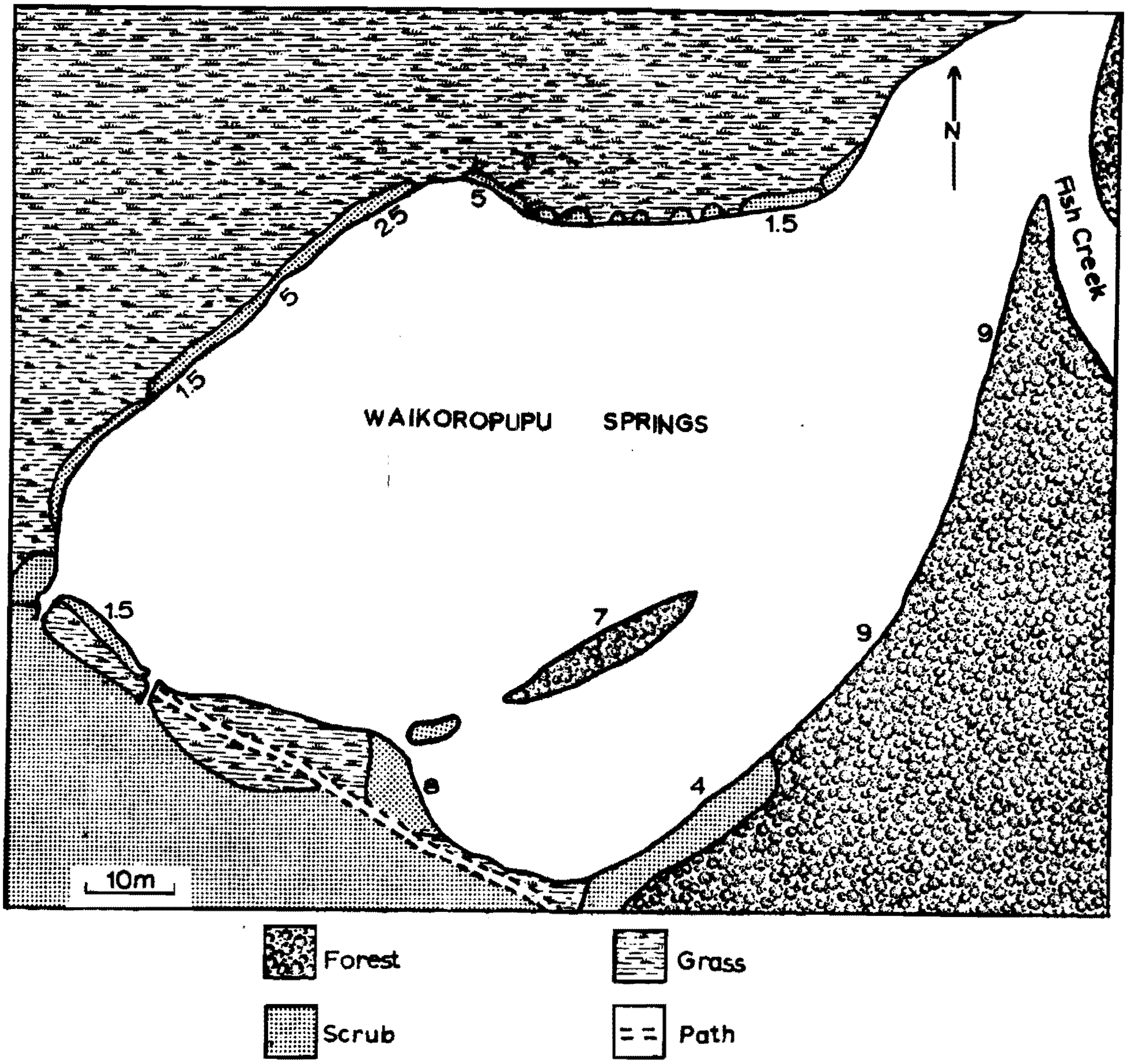


FIG. 2.2: Terrestrial vegetation types around Waikoropupu Springs (October 1971). Forest is predominantly rimu-totara-beech, scrub is manuka-kanuka-gorse and grass is mainly introduced species. Maximum height of vegetation at shoreline is indicated in metres.

TABLE 2.2: Species of plants surrounding Waikoropupu Springs in December 1971. Introduced species are marked by an asterisk. F indicates species found in forest, S indicates species found in scrub and Sh indicates species found around shoreline.

Cl.	Filicopsida
F	Phymatodes diversifolium (Willd.) Pic. Ser.
F	Blechnum capense (L.) Schlecht
F,S	Gleichenia cunninghamii Heward ex Hook.
Cl.	Spermatopsida
S.Cl.	Gymnospermae
F	Dacrydium cupressinum Lamb
F	Podocarpus totara G. Benn. ex D.Don
S.Cl.	Angiospermae
	Monocotyledones
Sh	Phormium tenax J.R. et G. Forst.
Sh	Cordyline australis (Forst. f.) Endl.
Sh	Cortaderia sp.
	Dicotyledones
Sh	*Ranunculus acris L.
F	Fuchsia excorticata J.R. et G. Forst.
F	Pittosporum eugenioides? A. Cunn
S	Leptospermum scoparium J.R. et G. Forst.
S	Leptospermum ericoides A. Rich
F	Metrosideros colensoi Hook. f.
F	Weinmannia racemosa Linn.f.
S	*Ulex europaeus L.
S	*Cytisus scoparius L.
F	Nothofagus fusca (Hook. f.) Oerst.
F	Nothofagus menziesii (Hook. f.) Oerst.
F	Pseudopanax crassifolium (Sol. ex A. Cunn.) C. Koch
F	Cyathodes fasciculata (Forst.f.) Allan
F	Cyathodes juniperina (J.R. et G. Forst.) Druce
F	Coprosma tenuicaulis Hook.f.
F,S	Coprosma robusta Raoul
F	Coprosma cunninghamii Hook.f.
Sh	*Myosotis caespitosa K.F. Schultz

Various species of bryophyte, lichen and native and introduced grass were not identified.

B. AQUATIC VEGETATION

SPECIES PRESENT

Sixteen species of algae were recorded from Waikoropupu Springs (Table 2.3).

TABLE 2.3: Species of algae recorded from Waikoropupu Springs over the period January 1970 to January 1972.

Cyanophyta
*_Entophysalis_ _rivularis_ Kutz.
*_Nostoc_ _parmeliodes_ Kutz.
Nostoc _verrucosum_ (L.) Vauch.
Microcoleus? sp.
Oscillatoria? sp.

Chlorophyta
Chaetophora _elegans_ (Roth.) Agardh
Spirogyra sp. (sterile)

Chrysophyta
Xanthophyceae
Vaucheria sp. (sterile)
Diatomaceae
Achnanthes sp.
Cocconeis _placentula_ Ehr.
Cymbella sp.
Gomphonema sp.
Navicula sp.
Synedra _ulna_ (Nitzch.) Ehr.

Rhodophyta
Batrachospermum sp.
Hildenbrandia _rivularis_ Liebm.

*First collected by Miss R. Mason on 7 March 1957 and identified by Dr. F. Drouet in October 1960 (E. A. Flint, pers. comm.).

Seven species of moss, three species of liverwort and five species of angiosperm (Table 2.4) were found in Waikoropupu Springs. The mosses and liverworts are native to New Zealand but three of the angiosperms are introduced.

TABLE 2.4: Species of aquatic plants, excluding algae, recorded from Waikoropupu Springs and five other cold springs in New Zealand on the dates indicated and classified as to growth form according to the scheme of Sculthorpe (1967). Introduced species are marked by an asterisk.

Growth form and species	SOUTH ISLAND			NORTH ISLAND		
	Waikoropupu Springs	Spring at L. Hayes	Three Springs	Otangeroa Springs	Hamurana Springs	Western Springs
Submerged bryophytes-mosses						
Acrocladium cuspidatum	x					
Cratoneuropsis relaxa	x		x			
Cyathophorum bulbosum	x					
Drepanocladus aduncus	x					
Drepanocladus fontinaliopsis						x
Echinodium hispidum	x					
Fissidens rigidulus	x	x				
Hypopterygium filiculaeforme	x					
Thamnium pandum					x	
Thiudiopsis furfurosa					x	
Submerged bryophytes-liverworts						
Lophocolea austrigena	x					
Lophocolea minor	x					
Neesioscyphus phoenicorhizus	x					
Riccardia sp.					x	
Ricciocarpus natans						x
Submerged angiosperms						
* *Lagarosiphon major*				x	x	
Myriophyllum elatinoides	x					
Myriophyllum propinquum					x	
Potamogeton sp.					x	
Emergent angiosperms						
* *Juncus microcephalus*	x					
* *Nasturtium microphyllum*	x	x	x			
* *Nasturtium officinale*				x	x	
Floating-leaved angiosperms						
* *Callitriche stagnalis*	x			x	x	x
Potamogeton cheesemanii				x		
Free-floating angiosperms						
Lemna minor	x	x		x		
* *Salvinia* sp.						x
Reference	an 1970 to eb 1972	Feb 1971	6 Feb 1971, 1 Oct 1972	4 Feb 1972	4 Aug 1970, 5 May 1971	8 Aug 1970 nd Johnstone 1972)

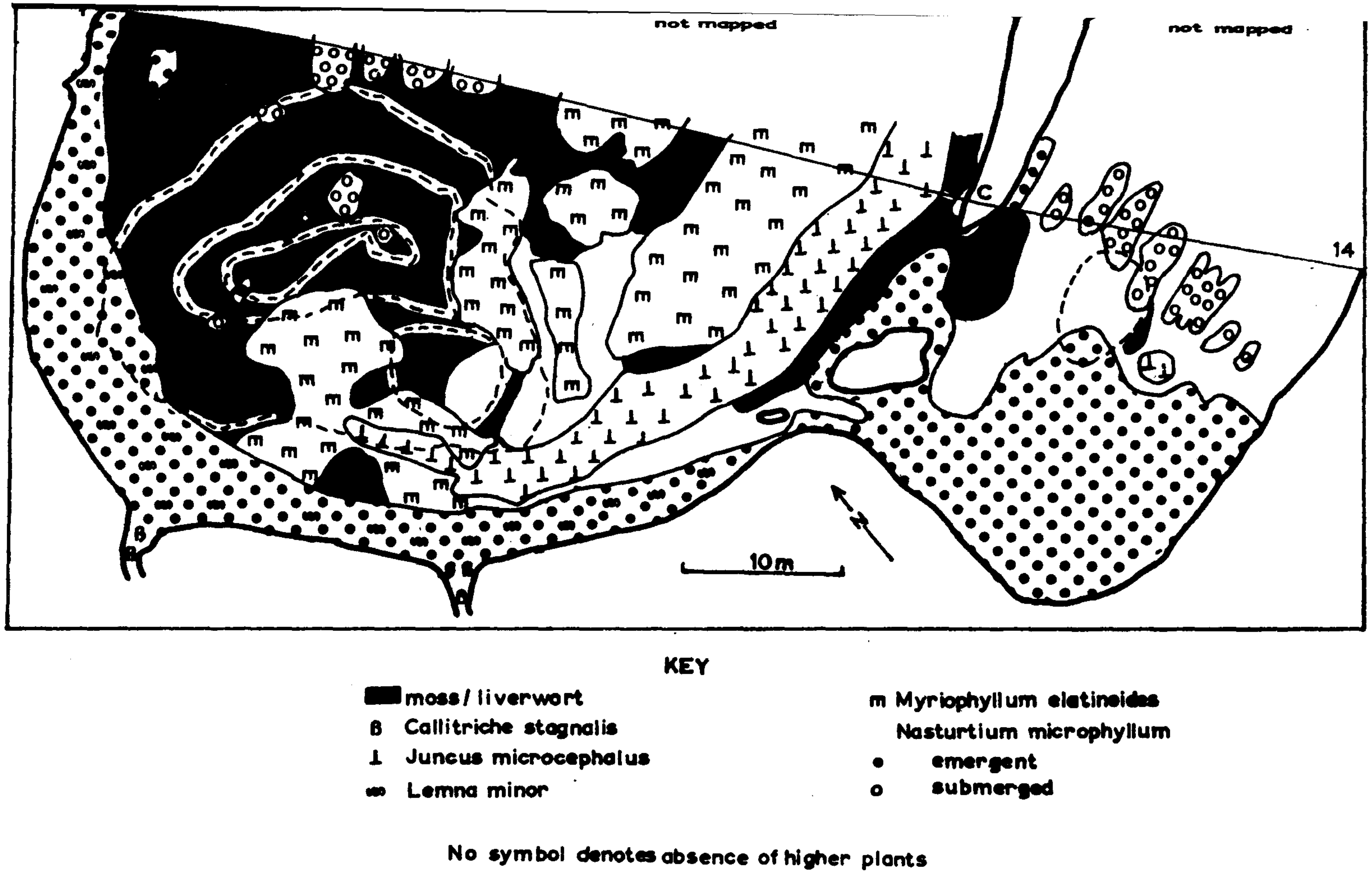


FIG. 2.3: Map of Waikoropupu Springs showing aquatic vegetation. Depth contours at 2 m intervals are indicated by dotted lines. The maximum area covered by emergent Nasturtium microphyllum during the study period is shown, as mapped on 28 July 1970. The area downstream of the lines joining points 1 and C, and C and 14 was not mapped.

DISTRIBUTION OF VEGETATION

Some species of bryophyte were found together but the distribution of bryophytes as a group and of each species of angiosperm was clearly defined and there were no transition zones between them. Many plants were common in shallow water including Nasturtium microphyllum (free-floating and submerged), Juncus microcephalus, bryophytes and algae (Fig. 2.3). Here, water velocities ranged from very slight to strong but the flow was stable (Part 1) and the shoreline of Waikoropupu Springs lacked the turbulence of wave action sometimes found on a lake shoreline. Deeper water at the bottom of the Springs (maximum depth of 6.9 m) was colonised by some algae, bryophytes and N. microphyllum (see below).

The map of aquatic vegetation (Fig. 2.3) shows that Waikoropupu Springs is a mosaic of plant species. This distribution of plants reflects the varied substrate and water velocity types within the Springs (see below). Plant distribution may be modified in places by the light climate which is a function of depth of the water. Species of plants restricted to a given substrate and water velocity type were termed characteristic species (the exclusive species of Poore 1955), as shown in Table 2.5. The distribution of individual species of plants is considered in detail under the heading "Notes on aquatic groups".

The angiosperms in Waikoropupu Springs cover a greater area than that covered by bryophytes (Table 2.6). Lemna minor, Juncus microcephalus, emergent Nasturtium microphyllum and Myriophyllum elatinoides all cover significant areas (11%, 7%, 16% and 16% respectively of the total area of the Springs). The moss Cratoneuropsis relaxa (9%) and "liver-

TABLE 2.5: Five substrate and water velocity types in Waikoropupu Springs with their commonly associated algae and higher plants. Characteristic species are marked with a C and epiphytic algae are marked E.

	Higher plants		Algae
(a) Boulders in a very strong water velocity (site 10)			
	none		_Entophysalis rivularis_
			Hildenbrandia rivularis
(b) Boulders in a moderate to strong water velocity and a small area of bedrock in a slight water velocity (sites 1, 2, 3, 4)			
C	_Cratoneuropsis relaxa_	C,E	_Spirogyra_ sp.
C	_Fissidens rigidulus_		_Entophysalis rivularis_
C	_Cyathophorum bulbosum_		_Hildenbrandia rivularis_
C	_Lophocolea austrigena_		
C	_Lophocolea minor_		
C	_Neesioscyphus phoenicorhizus_		
(c) Gravel in a slight to strong water velocity (sites 5, 6, 8, 9)			
C	_Juncus microcephalus_	E	_Synedra ulna_
C	_Myriophyllum elatinoides_	E	_Achnanthes_ sp.
C	_Nasturtium microphyllum_		
(d) Unstable sand and gravel in a slight to strong water velocity			
	none		none
(e) Silt and water of very slight velocity (site 7)			
C	_Nasturtium microphyllum_		none
C	_Lemna minor_		

TABLE 2.6: Area covered by various species of aquatic plants in Waikoropupu Springs over the period July 1970 to January 1972. For *Nasturtium microphyllum* (emergent), *Lemna minor* and the area devoid of bryophytes and angiosperms, mean values are given for the period July 1970 to January 1972 inclusive. The area of all other species is assumed constant. Introduced species are marked by an asterisk.

Species	Area (m^2) Main Spring	Dancing Sands	Total	Area of each species as % of area of Springs
Cratoneuropsis relaxa	160	0	160	9
Lophocolea spp. and associated spp.	330	16	346	19
Total bryophytes	490	16	506	28
* *Nasturtium microphyllum*				
(emergent)	192	97	289	16
(submerged)	31	26	57	3
Myriophyllum elatinoides	285	0	285	16
Lemna minor	192	0	192	11
* *Juncus microcephalus*	117	2	119	7
* *Callitriche stagnalis*	13	0	13	<1
devoid of bryophytes and angiosperms	203	298	501	28

wort" grouping of Lophocolea spp., Neesioscyphus phoenicorhizus and Cyathophorum bulbosum (about 19%) cover a total of 28% of the area of the Springs. (Although this bryophyte grouping includes the moss Cyathophorum bulbosum, it is dominated by liverworts and will be referred to as "liverwort"). Bryophytes are much more common in the Main Spring than in the Dancing Sands (Table 2.6) because there are no bedrock or boulder substrates in the Dancing Sands. Callitriche stagnalis and submerged Nasturtium microphyllum are not significant. A total of 501 m^2 (28%) of the area of the Springs, generally where the substrate is unstable, is devoid of bryophytes or angiosperms.

TRANSECTS

In Figs 2.4a and b, representative transects across Waikoropupu Springs from X to S and X to R (Fig. 2.1) are drawn. Fig. 2.4a (from left to right) shows Myriophyllum elatinoides swept over by the current and rooted in liverwort overlying bedrock; a bedrock area without bryophytes or angiosperms, and Juncus microcephalus rooted in a gravel substrate. Fig. 2.4b (from left to right) shows a boulder bank of moss/liverwort; Nasturtium microphyllum rooted in gravel at depth 6.5 m; bedrock covered in moss/liverwort; M. elatinoides rooted into moss/liverwort; boulders covered in moss/liverwort and finally, both submerged and emergent N. microphyllum with free-floating Lemna minor.

NOTES ON AQUATIC GROUPS

BACTERIA AND FUNGI

The total viable count of bacteria and fungi for water from the "principal" vent of Waikoropupu Springs was consistently low and varied from 1×10^0 to 2.3×10^5

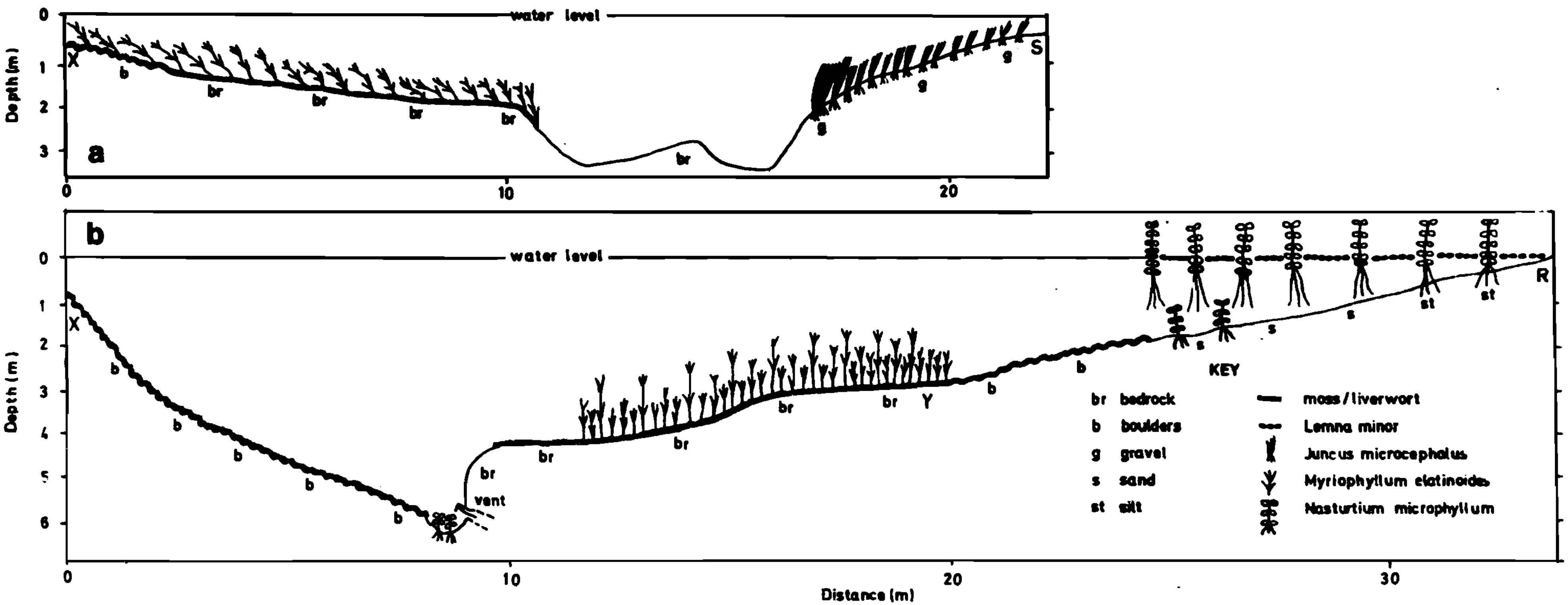


FIG. 2.4: Representative transects across Waikoropupu Springs to show growth forms of plants and their vertical distribution. Heights of plants are to scale.
a. Transect from X to stand S.
b. Transect from X to Y to R.

bacterial colonies/ml, with a mean value of 7.3×10^3/ml (Appendix 4). No correlation was observed between water discharge and bacterial count. Fewer than 5 fungal colonies/ml were recorded. Water from natural springs is usually relatively free of micro-organisms owing to the filtering effect of natural percolation through the surface rocks (Round, Hawker and Linton 1971).

Bacterial and fungal counts recorded from moss at site 1 and on watercress at site 7 were consistently higher than counts for the water but showed considerable variation both between duplicate samples and between sampling dates. Total viable count on moss at site 1 varied from 1.7×10^5 to 1.6×10^8 bacterial colonies/g dry wt of plant, with a mean value of 1.7×10^7/g dry wt of plant (Appendix 4). Total viable count on watercress at site 7 varied from 7.0×10^5 to 1.6×10^9 bacterial colonies/g dry wt of plant, with a mean value of 1.6×10^8/g dry wt of plant (Appendix 4). Fewer than 8×10^4 fungal colonies/g dry wt of plant were recorded.

ALGAE

The most abundant algae in Waikoropupu Springs were Rhodophyta, Cyanophyta and in summer, Diatomaceae. Less common forms included Chlorophyta and Xanthophyceae (Table 2.3). No planktonic algae were seen in the Springs, apart from the occasional benthic form which had been torn loose from the substrate.

No species of algae were exclusive (Poore 1955) to a given substrate type and water velocity. However, many of the attached algae showed some specificity with regard to substrate. Some genera were epilithic (i.e. on bedrock): <u>Nostoc</u>, <u>Microcoleus</u>, *Oscillatoria*, *Entophysalis*, *Batrachospermum*, *Hildenbrandia* and occasionally *Achnanthes* and *Synedra*. Others such as *Vaucheria* and sometimes *Nostoc* were epipelic (i.e. on sand or gravel). Other genera were epiphytic (i.e. on plants): *Microcoleus*, *Chaetophora*, *Spirogyra*, *Cocconeis*, *Achnanthes*, *Cymbella*, *Gomphonema*, *Navicula*, *Synedra* and sometimes *Oscillatoria*, *Vaucheria* and *Batrachospermum*. Some epiphytic algae exhibited host specificity. *Spirogyra* sp. was found only on the mosses *Cratoneuropsis relaxa* and *Fissidens rigidulus*; *Vaucheria* sp. was found only on the rush *Juncus microcephalus* in a slight water velocity and *Microcoleus* sp. only on *Nasturtium microphyllum* at the bottom of the Springs. Epiphytic diatoms, of which *Synedra ulna* and *Achnanthes* sp. were the most common, were found in large numbers on both *J. microcephalus* and *Myriophyllum elatinoides*.

Water velocity may have restricted the distribution of some groups in the Springs. Cyanophyta and Chlorophyta were found in slight to moderate water velocities whereas Rhodophyta grew where water velocities of up to 150 cm/s were recorded.

Some genera in the Springs had limited vertical distributions. *Spirogyra* sp., *Chaetophora* sp., *Vaucheria* sp. and *Nostoc* spp. were found only in water less than 3.5 m deep whereas *Microcoleus* sp., *Entophysalis rivularis*, *Hildenbrandia rivularis*, *Batrachospermum* sp. and the jointly-occurring diatoms *Synedra ulna* and *Achnanthes* sp. were found to a depth of 6.9 m at the bottom of the Springs.

Seasonal changes in abundance

At Waikoropupu Springs, algal abundance appeared to increase during summer and decrease during winter. The only

PLATE 2.2: Underwater view of site 1 in the Main Spring showing boulders covered in the moss Cratoneuropsis relaxa. In the background, at left, Nasturtium microphyllum (watercress), in the centre, Juncus microcephalus (rush) and at the water surface, floating N.microphyllum. Patterns of shade on the bottom are due to the rippling water surface.

marked seasonal change in species composition in the Springs was that *Synedra ulna* and *Achnanthes* sp. were not observed in winter.

BRYOPHYTES

Cratoneuropsis relaxa

At Waikoropupu Springs this is the most common moss, growing at depths from 0.2-6.9 m but only where the water velocity is less than 60 cm/s i.e. less than strong. It is found on boulders (Plate 2.2) or bedrock and infrequently on sand and gravel. This moss is often found growing in springs, on wet banks and on rocks and boulders in streams (Sainsbury 1955).

Fissidens rigidulus

F. rigidulus is sometimes found submerged on stones in streams (Sainsbury 1955). In the Springs it is found on boulders in isolated patches in the *Cratoneuropsis relaxa* carpet. It is difficult to identify this moss while SCUBA diving, so its vertical distribution is uncertain but probably extends from about 0.2-2 m.

Cyathophorum bulbosum

In Waikoropupu Springs, the mature stages could be determined underwater since filaments reached a length of 12 cm but its immature stages could only be distinguished from the jointly-occurring liverwort species using a microscope at high magnification. According to Sainsbury (1955), this moss is found on damp humus, logs or damp rock in shade. In the Springs it was found only with liverworts (below) which cover the extensive boulder bank formed on the downstream side of the Main Spring basin (Fig. 1.5). Mature stages of *C. bulbosum* are found at depths from 10 cm to about 3 m where water velocities

Lophocolea austrigena, *Lophocolea minor* and *Neesioscyphus phoenicorhizus*

It was not possible while SCUBA diving to distinguish between these species of liverwort so the distribution of the individual species in Waikoropupu Springs is not known. *Lophocolea* spp. are the dominant liverworts in the Springs and occur in water from 0.1-6.9 m deep (Plate 2.3). They are found in water velocities up to about 140 cm/s (which are faster than the velocities where the moss *Cratoneuropsis relaxa* is found) and form a cover 1.5-2.5 cm thick on boulders and occasionally on bedrock. *Neesioscyphus phoenicorhizus* was collected from a boulder substrate in fast flowing water less than 1 m deep.

It has been suggested that *Lophocolea bidentata* has an intimate symbiotic relationship with various mosses (Richards 1932). The close spatial relationship observed between *Lophocolea* spp. and the moss *Cyathophorum bulbosum* in Waikoropupu Springs also suggests the possibility of such a relationship.

The bryophytes *Acrocladium cuspidatum*, *Drepanocladus aduncus*, *Echinodium hispidum* and *Hypopterigium filiculaeforme* were not common in the Springs.

ANGIOSPERMS

Callitriche stagnalis - starwort

Starwort is a native of Europe and North Africa, first recorded in New Zealand in 1884 where it is now common and widespread in fertile waters (Mason 1970). At Waikoropupu Springs it is restricted to the two inflows (Fig. 2.3) which discharge only after heavy rain with a water velocity generally less than 10 cm/s. The plants are rooted in sand overlain by silt where the water depth is less than 35 cm. Stems are up to

40 cm long and the leaves form a mat on the surface of the water.

Juncus microcephalus

This rush is a native of Mexico and South America. It was first collected in New Zealand in 1929 (R. Mason, pers. comm.) but the date of its introduction to Waikoropupu Springs is not known. Normally a plant of damp ground, at the Springs it forms a narrow band on gravel in fast flowing water of depth 0.1-2.1 m (Fig. 2.3). Its stems were usually 0.3 m to 0.5 m long but the maximum recorded length was 1.25 m (Plate 2.2).

Lemna minor - duckweed

Duckweed is found in almost all temperate and tropical regions, floating on or beneath the water surface. It occurs in the Springs only where the water velocity is less than 10 cm/s and where emergent and free-floating watercress prevent it from being washed away (Fig. 2.3). Following removal of watercress shoots from an area of 1 m^2 in the Main Spring on several occasions, it was estimated that *L. minor* covered between 85 and 95% of the surface of the water. *Lemna minor* is not found among the emergent watercress of the Dancing Sands, but the reason for its absence is not known.

Myriophyllum elatinoides - water milfoil

The native water milfoil is found throughout New Zealand from sea-level to 1,200 m, often growing entirely submerged. Allan (1961) recorded *M. elatinoides* from "ponds, lakes and slow flowing streams" but it is found in Waikoropupu Springs in moderate to strong water velocities, firmly rooted in gravel, sand or a layer of liverwort over bedrock, in water of depth 0.2-5.0 m (Fig. 2.3).

PLATE 2.3: Nasturtium microphyllum (watercress) growing at depth 6.5 m in the Main Spring. The measuring rod is marked at 20 cm intervals. In the background, boulders covered in the liverworts Lophocolea spp.

This species exhibits a wide range of growth form. At the Springs, stem lengths of 5-100 cm (rarely 250 cm) were measured whereas stem lengths recorded by Allan (1961) were 5-50 cm (rarely 100 cm). He also recorded that the upper emergent leaves are entire, sessile, ovate-oblong and obtuse but emergent leaves at Waikoropupu Springs were pinnasect with fine segments.

Nasturtium microphyllum - watercress

Nasturtium microphyllum was introduced from England to Christchurch in about 1850. The initial spread of the plant was rapid (Thompson 1922) and it was common in the Takaka Valley from as early as 1916 (A. G. McFarlane, pers. comm.). Photographs of Waikoropupu Springs taken about 1940 show no evidence of the plant and it was not recorded from there until 1957 (R. Mason, pers. comm.).

At the present time, watercress grows around the edge of the Main Spring and extends over the Dancing Sands. Some plants float with roots trailing whilst other plants are rooted in gravel overlain by silt (Fig. 2.4). The stems of these plants are up to 2.1 m long. The floating and emergent plants have 5-11 leaflets/leaf (Fig. 2.5a). (See also section on seasonal changes in angiosperms). Watercress at Waikoropupu Springs is free from the diseases (Crisp 1970) and pests, such as the caddisfly *Limnephilus lunatus* (Gower 1967), that occur on watercress in the United Kingdom.

Watercress usually grows as an emergent plant, rooted in the substrate. Specimens similar in appearance to *N. microphyllum* grow entirely submerged in the Springs at depths ranging from 1.0-6.5 m (Plate 2.3). These never flower, making identification on the basis of flowers and seed pods impossible but because *Nasturtium* spp. have been recorded submerged in other New Zealand localities (Mason 1970) it was assumed that the submerged specimens were *N. microphyllum*. The present study also recorded *N. microphyllum* growing submerged in the Avonhead Springs outflow, Christchurch (water depth 50 cm) and *N. officianale* growing submerged in the spring-fed Little Waipa River, Putaruru (water depth 75 cm) and in Hamurana Springs, Rotorua (water depth 75 cm). Nevertheless, the presence of *N. microphyllum* growing to a depth of 6.5 m is unusual and may be related to the clarity of the Waikoropupu Springs water, although the light requirements of submerged watercress are not known.

Several patches of watercress (total area 57 m^2), growing submerged in the Main Spring and Dancing Sands to a maximum water depth of 6.5 m, exhibited a growth form different to that of emergent and floating watercress at the surface (Table 2.7).

TABLE 2.7: Growth form of *Nasturtium microphyllum* at two depths in Waikoropupu Springs.

Depth (m)	Maximum leaflets/ leaf	Maximum internode distance (cm)	Maximum leaf length (cm)	Maximum stem thickness (mm)
at surface	11	14.0	28.8	11
6.5	5	5.0	13.7	2

Watercress submerged in water of depth 3 m had 1-5 (generally 5) leaflets per leaf and stems reaching a length of 1 m. It was rooted in gravel between boulders. Watercress at the bottom

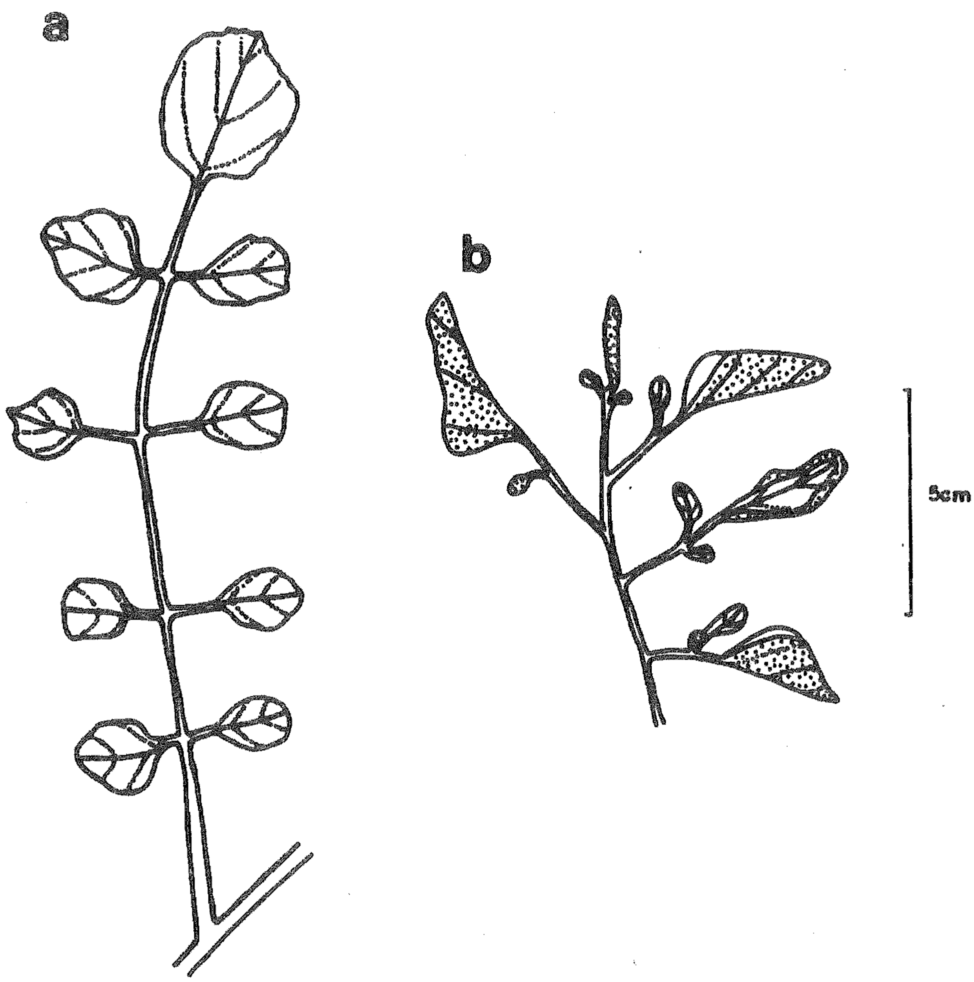


FIG. 2.5: Growth form of submerged Nasturtium microphyllum in Waikoropupu Springs in summer. The undersides of the leaves are shaded.

a. Leaf from depth 0.1 m
b. Shoot from depth 6.5 m

of the Springs (depth 6.5 m) had 1-5 (generally 3) leaflets per leaf (Fig. 2.5b) and stems reaching a length of 0.4 m. It was rooted in gravel. The leaflets of watercress submerged at a depth of 3 m were much thinner than those from watercress that was emergent. Leaflets from watercress growing at depth 6.5 m were a bright dark green and so thin that they were always rolled up. The length of the midrib between the leaflets, internode distance, leaf length and stem thickness were much greater in watercress that was emergent than growing submerged at depth 6.5 m (Table 2.7).

SEASONAL CHANGES IN BRYOPHYTES AND ANGIOSPERMS

At Waikoropupu Springs, plants growing completely submerged in water more than 1 m deep e.g. species of moss and liverwort, *Myriophyllum elatinoides* and *Nasturtium microphyllum* did not show seasonal changes in growth form that were visible to the underwater observer. However, there were obvious seasonal changes in growth form of various species of angiosperms growing in water less than 1 m deep.

Juncus microcephalus

Juncus microcephalus shoots emerged from shallow water from November 1970 to mid May 1971, and again in late October 1971. These shoots reached a height of 25 cm above the water surface. A fall in water level of the Springs could not be responsible for this, as the maximum water level fluctuation over the study period was 9 cm. *Juncus microcephalus* flowers appeared from late November to early May in both 1970-71 and 1971-72.

Nasturtium microphyllum in shallow water

This species, when emergent or submerged in water less than about 1 m deep, showed several seasonal changes in growth form: changes in the number of leaflets per leaf, length of internodes and colour of the leaves. Similar changes were observed in the summers of 1970-71 and 1971-72.

The number of leaflets per leaf was uniform for the first ten leaves from the apex downwards on any given shoot and did not vary much between shoots on a given sampling date. The number increased from a winter modal value of 3, 5, or 7 (early April to early August) to a summer modal value of 9 or 11 (mid-October to mid-February).

Measurements made in November 1970 on emergent watercress showed that internode length on a single stem could vary from 0.9-14.0 cm, the length depending on the distance of the internode from the apex. Observations made in the field suggested that the internodes of the main stem and the midrib between the leaflets began to elongate in late October.

Watercress shoots emerged from shallow water between mid-October 1970 and mid-May 1971 and from late October 1971 until at least April 1972. Watercress flowers were first observed in early December 1970 and late November 1971. Flowering continued until mid-May in 1971 and seed pods were present from early January to late May 1971. Shoots turned yellow in some areas of the Main Spring from December 1970 - March 1971 and from January - April 1972 and in the Dancing Sands from November - December 1971. Crisp (1970) mentioned yellow cress in commercial beds of N. officinale, the cause of, and cure for which, is not known.

Myriophyllum elatinoides

Shoots of M. elatinoides growing in shallow water were at the surface in the Main Spring from early November 1970 - April 1971, and again from mid-November 1971 - April 1972.

BIOMASS

Dry weight and organic matter

Root material was included in all determinations of the biomass of angiosperms in the Springs. A significant part of the dry weight of angiosperm samples consisted of root material e.g. J. microcephalus, 19% (single determination); M. elatinoides, 23% (single determination); and free-floating N. microphyllum 40 $\pm$ 6% (95% confidence intervals based on 17 determinations of watercress free of silt). Some estimates of total biomass, and root material as a percentage of total biomass, were too high when not all the substrate could be removed from the roots during sorting of samples without loss of root material, e.g. J. microcephalus, root material as a percentage of total biomass - 49% (single determination from a substrate of fine gravel).

Biomass determinations of the major species of aquatic plant in Waikoropupu Springs are summarised in Table 2.8. Biomass of submerged plants varied markedly depending on the substrate type, water velocity and light climate, e.g. the biomass of Myriophyllum elatinoides varied from 190 g dry wt/m^2 (estimated to be the minimum biomass) on bedrock to 1300 g dry wt/m^2 (estimated to be the maximum biomass) on sand. The mosses Cratoneuropsis relaxa and Fissidens rigidulus growing on a vertical concrete face showed a biomass of 430 g dry wt/m^2 (mean of 80 determinations) whereas one of these species growing on a horizontal surface of sandstone boulders at a similar depth (site 1) reached a much greater biomass (1100 g dry wt/m^2 - mean of 4 determinations). The liverworts Lophocolea spp. and Neesioscyphus pheonicorhizus and the moss Cyathophorum bulbosum growing together on boulders at site 4 had a mean

TABLE 2.8: Biomass of major species of plants in Waikoropupu Springs. Sampling sites are shown in Fig. 2.1 and details are given in Table 2.1.

Species	Date and number of determinations	Mean dry weight (g/m^2)	Location and other notes
Algae			
Spirogyra sp.	27 Jun 1971 (1)	2	site 1
	19 Feb 1972 (1)	220	site 1
	Jan 1971-Feb 1972 (12)	69	site 1
Bryophytes			
Cratoneuropsis relaxa	24 Oct 1971 (4)	1100	site 1
	4 Jan 1972 (1)	1100	sand, 3 m with *Myriophyllum*
	5 Oct 1970 (1)	530	site 2
	3 Apr 1971 (1)	920	site 2
Cratoneuropsis relaxa) *Fissidens rigidulus*)	Dec 1970-Feb 1972 (80)	430±300	site 3
Lophocolea spp.)	25 Oct 1971 (4)	610 (340-1000)	site 4
Neesioscyphus sp.)	30 Jul 1972 (6)	560 (400-690)	site 4
Cyathophorum bulbosum)	4 Jan 1972 (4)	420 (340-570)	boulders, 4.5 m
Angiosperms			
Juncus microcephalus	25 Oct 1971 (2)	520 (330-710)	site 5, not flowering
	6 Mar 1971 (1)	>870	site 5, flowering
	19 Mar 1972 (1)	1300	site 5, flowering
Lemna minor	10 Jan 1971 and 7 Feb 1971 (4)	70 (65-75)	site 7, seasonal max. biomass
	27 Jun 1971 and 29 Aug 1971 (5)	28 (13-47)	site 7, seasonal min. biomass
Myriophyllum elatinoides	1 May 1971 (1)	190	bedrock, 1.5 m
	4 Jan 1972 (1)	1400	sand, 3 m with moss
Nasturtium microphyllum (emergent)	25 Jul 1971 (3)	950 (750-1100)	site 7, minimum biomass during sampling period
	2 May 1971 (3)	1500 (1300-1700)	site 7, seasonal max. biomass 1970-71
	19 Feb 1972 (2)	1550 (1500-1600)	site 7, seasonal max. biomass 1971-72
(submerged)		est. 750	site 8
		est. 250	site 9

biomass of only 585 g dry wt/m^2. Any differences in biomass of bryophytes between sites 1 and 4 were not attributable to differences in size or shape of boulders which made up the substrate. The mean standard area of samples collected at site 1 in Waikoropupu Springs was 282 $\pm$ 52 cm^2 (95% confidence interval) and of samples at site 4, 283 $\pm$ 71 cm^2. There was no significant difference ($t = 2.1$, $df = 14$, $P > 0.05$) between these standard areas. The mean ratio of standard area/height of the boulders sampled was also not significantly different ($t = 0.02$, $df = 14$, $P > 0.05$) between sites 1 and 4 (38 and 33 respectively). Differences in biomass between sites 1 and 4 might be due to differences in water velocity and hence the stability of the substrate.

The biomass of plants was generally lower in deep water than in shallow water. Cratoneuropsis relaxa growing at a depth of 4.3 m had a maximum biomass of 920 g dry wt/m^2, slightly less than that recorded in shallower water. The biomass of submerged N. microphyllum (depth 6.5 m) was not measured directly as the bed would have been disturbed by extensive sampling. However, its dry weight was estimated to be about 250 g/m^2 on the basis that stem length (40 cm) was about one-quarter that of the emergent N. microphyllum (1.6 m), number of stems per square metre was comparable and growth form was similar to that of emergent N. microphyllum in mid-winter when the biomass of the latter was 950 g dry wt/m^2.

The ash content of the common plant species at Waikoropupu Springs varied from 11-31% of the dry weight and is summarised in Table 2.9. Variation in ash content of shoots of N. microphyllum (depth 6.5 m) between sampling dates was noted but not further investigated.

TABLE 2.9: Ash content of major species of bryophytes and angiosperms from Waikoropupu Springs.

Species		Sample depth (m)	Date	Mean ash content as % of dry weight and number of determinations (in brackets)
Bryophytes				
Cratoneuropsis relaxa		0.8	25 Oct 1971	20 (4)
Fissidens rigidulus		1.5	25 Oct 1971	21 (2)
Lophocolea spp.) Neesioscyphus phoenicorhizus)		1.0	25 Oct 1971	27 (2)
Angiosperms				
Lemna minor whole plant		0	25 Oct 1971	13 (4)
Juncus microcephalus	shoots	0.5	25 Oct 1971	11 (2)
	roots	0.5	25 Oct 1971	30 (2)
Nasturtium microphyllum	shoots	0	25 Oct 1971	16 (2)
		0	16 Jan 1972	16 (2)
		3.0	16 Jan 1972	20 (2)
		6.5	25 Oct 1971	31 (4)
			16 Jan 1972	19 (2)
	roots	0.3	25 Oct 1971	19 (1)
Myriophyllum elatinoides	shoots	2.0	25 Oct 1971	11 (2)

Seasonal changes in biomass

Biomass of the alga Spirogyra sp. growing on Cratoneuropsis relaxa varied from 2 g dry wt/m^2 in June 1971 to 220 g dry wt/m^2 in February 1972 with a mean of 69 g dry wt/m^2 (Table 2.8).

No seasonal changes in the biomass of submerged higher plants were visible to the underwater observer. Four-weekly biomass measurements of the mosses Cratoneuropsis relaxa and Fissidens rigidulus at site 3 showed that seasonal changes were not great (Fig. 2.6) and no significant differences were found between either summer 1970-71 or summer 1971-72 and winter 1971 (U = 104, 119 respectively, a = 3, n = 16, $p > 0.05$)

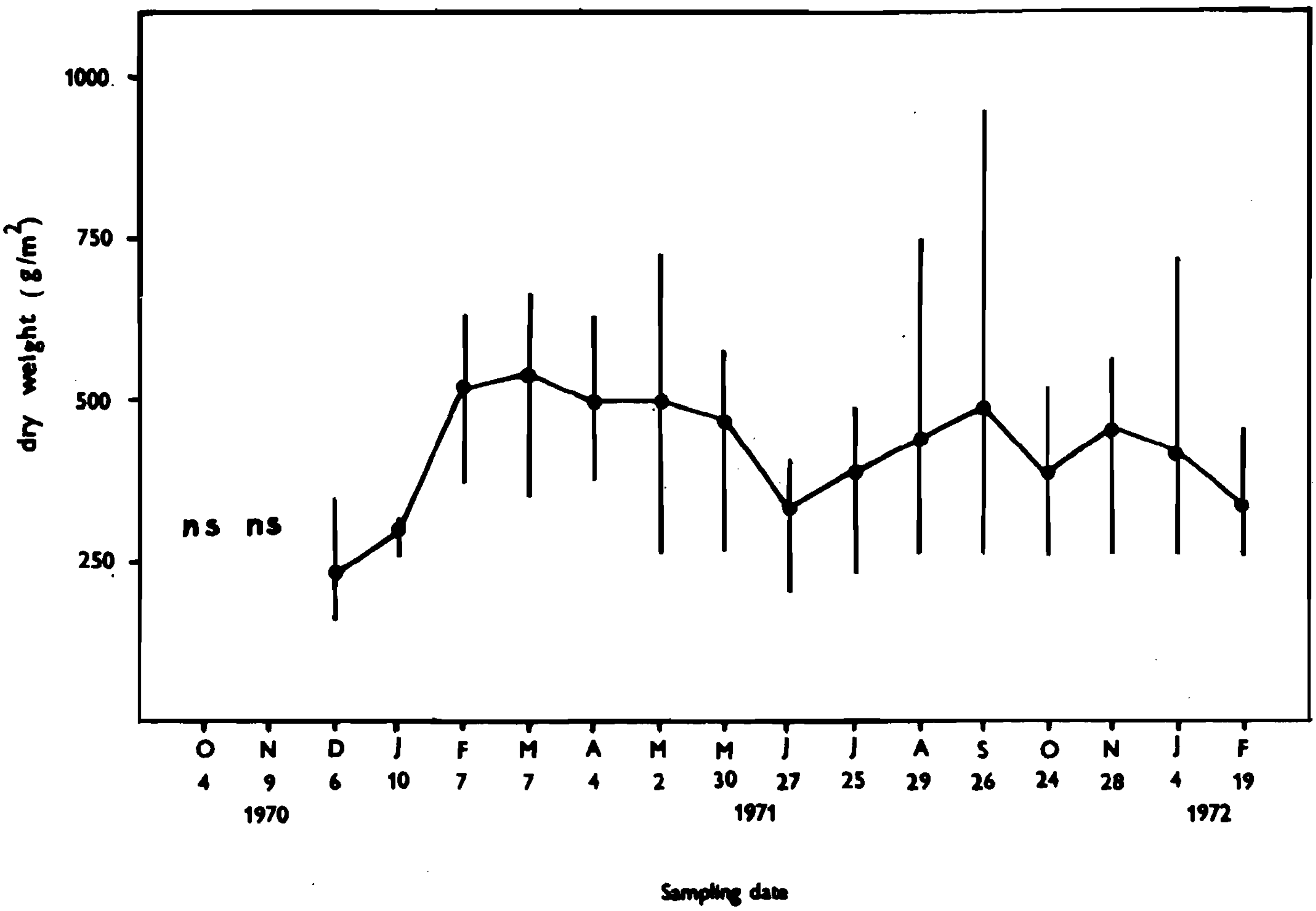


FIG. 2.6: Seasonal changes in the biomass of the mosses <u>Cratoneuropsis relaxa</u> and <u>Fissidens rigidulus</u> at site 3 in Waikoropupu Springs. Solid line joins mean values and vertical bars indicate range of values obtained. "ns" denotes no sample taken on that date.

(Sokal and Rohlf 1969, p. 397).

All emergent and free-floating higher plants in Waikoropupu Springs showed some seasonal changes in biomass (Table 2.8). The limited data suggest that the biomass of both J. microcephalus and L. minor was greater in summer than winter. Seasonal changes in biomass of watercress (N. microphyllum) were obscured in summer 1970-71 by heavy cattle grazing in November 1970 (Fig. 2.7). Losses between 4 October and 9 November 1970, due to grazing, were about 30% of the biomass. The seasonal maximum biomass (Table 2.8) was reached in early May 1971 (autumn). Losses due to cattle grazing occurred again in July 1971 but a considerable biomass persisted throughout the winter. During spring and summer 1971 biomass increased and reached a seasonal maximum in February 1972 (Table 2.8), after which sampling was discontinued.

The proportion of roots to shoots varied irregularly throughout the sampling period with roots forming between 36% and 63% of the total biomass of the watercress samples.

PRODUCTIVITY OF FREE-FLOATING NASTURTIUM MICROPHYLLUM

The total area of the emergent watercress beds changed during the study period (Table 2.10a). On 4 October 1970 the beds in the Main Spring covered 356 m^2. Following grazing of these beds by cattle in November 1970, they became increasingly unstable and a gradual loss of watercress downstream (110 kg) resulted so that by 1 May 1971 the area of the beds was 108 m^2. Production over this period was not estimated because of loss of material downstream. Further grazing of the beds by cattle took place early in July 1971 but after this the beds appeared to stabilise and began to increase in area so that by 19 Feb-

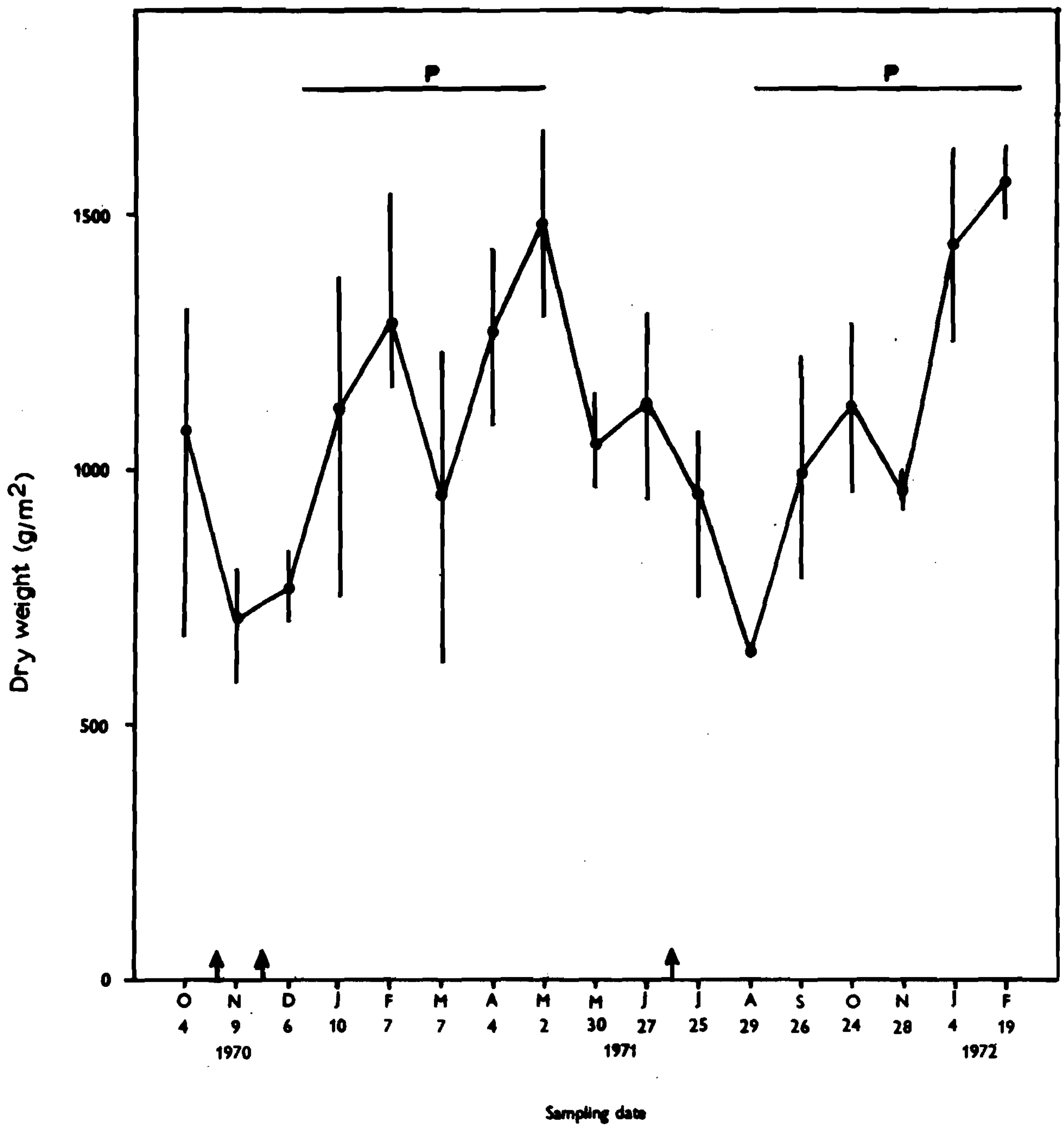


FIG. 2.7: Seasonal changes in the biomass of emergent <u>Nasturtium microphyllum</u> in the Main Spring. Arrows indicate dates on which cattle were seen grazing beds. Solid line joins mean values and vertical bars indicate range of values obtained. Horizontal lines labelled "P" indicate periods of productivity measurements.

ruary 1972 they covered 225 m^2. During the same period production was 12.9 m.t/ha of organic matter (Table 2.10b). On 4 October 1970 the watercress beds in the Dancing Sands covered 232 m^2 but a local resident removed the entire bed on 24 December 1970. The beds soon re-established and rapidly increased in area from 6 February 1971 onwards, so that they had fully regrown by 28 November 1971 (242 m^2). Production over this period amounted to 8.8 m.t/ha of organic matter (Table 2.10b).

The production values of 12.9 m.t/ha for the Main Spring and 8.8 m.t/ha for the Dancing Sands were obtained from sampling periods of less than one year. These values can therefore be considered as minimum estimates of net annual production.

Because of the continual loss of plant material from the study area, the productivity of N. microphyllum in the Main Spring could not be calculated over the period December 1970 to May 1971 in spite of marked increases in biomass per unit area (Table 2.10a). Between July 1971 and February 1972, values for productivity ranged from a minimum of -0.2 to a maximum of 17.2 g organic matter/m^2.day (Table 2.10a). The negative value obtained between October and November 1971 coincided with the dying back of the plants prior to full scale flowering. The maximum value was obtained over a 35 day period of high temperatures and high levels of bright sunshine (Fig. 1.2). Values for the productivity of N. microphyllum over periods of seven and nine months were 6.1 g organic matter/m^2.day in the Main Spring (July 1971 to February 1972) and 2.9 g organic matter/m^2.day in the Dancing Sands (February to November 1971) (Table 2.10b).

TABLE 2.10: Production and productivity of free-floating <u>Nasturtium microphyllum</u> at Waikoropupu Springs. i) Main Spring, 1970-1971; ii) Main Spring, 1971-1972; iii) Dancing Sands, 1972. Cattle grazed the beds of the Main Spring prior to 6 December 1970 and just prior to 25 July 1971 but were excluded during the periods covered by these measurements. N.D. indicates no data due to loss of watercress downstream.

a. Results for each sampling date.

Sampling date	Area of bed (m^2)	Mean bed area between sampling dates (m^2)	Biomass (dry weight) Mean of samples (g/m^2)	Biomass (dry weight) Bed (kg)	Biomass change between sampling dates. Dry wt. (kg)	Productivity (g/m^2.day) Dry weight	Productivity (g/m^2.day) Organic matter
i. Main Spring							
6 Dec 1970	356		763	271			
		320			45		
10 Jan 1971	285		1108	316			
		274			24		
6 Feb 1971	263		1293	340		N.D.	N.D.
		225			-166		
6 Mar 1971	186		937	174			
		186			61		
4 Apr 1971	186		1263	235			
		147			-74		
1 May 1971	108		1488	161			
ii. Main Spring							
25 Jul 1971	101		947	96			
		129			61	7.5	6.2
26 Sep 1971	157		1003'	157			
		157			19	3.5	2.9
24 Oct 1971	157		1122	176			
		171			-1	-0.2	-0.2
28 Nov 1971	184		950	175			
		201			153	21.0	17.2
4 Jan 1972	218		1421	310			
		222			43	4.2	3.4
19 Feb 1972	225		1568	353			
iii. Dancing Sands							
6 Feb 1971	208		0	0			
		225			241	3.5	2.9
28 Nov 1971	242		996	241			

b. Results for each sampling period

Sampling period	Mean area of bed during sampling period (m^2)	Change in biomass of bed during sampling period. dry wt. (kg)	Production organic matter (m.t/ha)	Productivity organic matter (g/m^2.day)
i. 6 Dec 1970 to 1 May 1971	232	-110	N.D.	N.D.
ii. 25 Jul 1971 to 19 Feb 1972	163	257	12.9	6.1
iii. 6 Feb 1971 to 28 Nov 1971	225	241	8.8	2.9

COMPARISON OF THE NEW ZEALAND COLD SPRINGS STUDIED

Species of bryophytes and angiosperms in six New Zealand cold springs were recorded in Table 2.4. The numbers of species recorded from each spring varied, and depended not only on the number of species present, but also on the intensity of collection.

The mosses Cratoneuropsis relaxa, Drepanocladus spp. and Fissidens rigidulus were found submerged in two of the springs studied. Other species of bryophyte occurred, each in only one spring (Table 2.4) but the greatest number of species was found in Waikoropupu Springs.

No submerged angiosperms grew in the spring at L. Hayes nor in Three Springs as the water was too shallow. Native species of Myriophyllum (M. elatinoides and M. propinquum) and of Potamogeton (including P. cheesemanii) were found in several of the springs studied. Lemna minor occurred in all the cold springs that had areas of calm water. The introduced Callitriche stagnalis grew in most of the springs listed but the most widespread plants were the introduced watercresses, Nasturtium microphyllum in the South Island and N. officinale in the North Island. Juncus microcephalus, also introduced, was found only in Waikoropupu Springs. Two other introduced species were restricted to North Island springs, i.e. Salvinia sp. and the oxygen weed Lagarosiphon major. Most angiosperms in the springs studied, whether emergent or submerged, were firmly attached to the substrate, which enabled them to withstand the moderate to very strong water velocities. Both the floating-leaved plants were restricted to calm water in the springs.

DISCUSSION

Species of algae in cold springs are generally similar to those in running water (Round 1965). The red alga Batrachospermum sp. is the only common macroscopic alga in springs (Round 1965) and Kühn (1940) recorded it from cold springs in Austria. It is common in Waikoropupu Springs but its presence was not investigated in other cold springs in New Zealand. Batrachospermum spp. require free carbon dioxide as a source of carbon for photosynthesis (Ruttner 1960) and groundwaters frequently contain levels of free carbon dioxide in excess of atmospheric equilibrium (e.g. Waikoropupu Springs - 5.8 g/m^3). The red alga Hildenbrandia is usually found in cold and torrential streams (Prescott 1969). Its occurrence near sea-level at Waikoropupu Springs is therefore unusual, although Botosaneanu and Negrea (1961) recorded it near sea-level in cold springs on the Plain of Rumania. Red algae are not as common in Silver Springs (Whitford 1956) as in Waikoropupu Springs, perhaps because the former has a higher temperature (22°C cf. 12°C) and lower water velocities.

Both diatoms and blue-green algae were common in Waikoropupu Springs. Round (1965) recorded that the diatoms Achnanthes and Denticulata are common in springs, perhaps because of the high pH, which may also favour blue-green algae (Prescott 1969). Three common diatoms and a yellow-green alga (Synedra ulna, Cocconeis placentula, Achnanthes sp. and Vaucheria sp.) found in Waikoropupu Springs are also common in Silver Springs which is another spring of the hard fresh-water type (Whitford 1956).

Aquatic mosses and liverworts were not common in the cold springs studied in New Zealand, except for Waikoropupu Springs. Several genera of moss collected in the Springs are frequent inhabitants of N.Z. streams (Drepanocladus, Fissidens and Cratoneuropsis) (Allison and Child 1971). The distribution of aquatic mosses may be limited by two factors - the availability of free carbon dioxide in the water (Richards 1932) and a suitable substrate of bedrock, boulders or stones (see below).

Small deposits of travertine ("tuf") were found at the base of the moss Cratoneuropsis relaxa in Waikoropupu Springs but deposits were rarely found associated with algae or liverworts in the Springs. Travertine deposition results from loss of carbon dioxide which is necessary to keep calcium bicarbonate in solution. Carbon dioxide is lost to the atmosphere as equilibrium is restored below the spring source and is also removed by aquatic mosses during photosynthesis (Richards 1932).

In Waikoropupu Springs, the liverworts Lophocolea spp. and Neesioscyphus phoenicorhizus were well developed over large areas of substrate although it is rare for liverworts to be important members of submerged communities in running waters (Hynes 1970).

In the New Zealand cold springs studied, a few native angiosperms belonging to the genera Myriophyllum and Potamogeton were found and also a number of introduced angiosperms of which the genus Nasturtium was the most widespread. Species of watercress are characteristic of cold springs (Pennak 1953) and emergent forms have been recorded from many temperate cold springs around the world (Minckley 1963; Crisp 1970). The two Nasturtium (watercress) species were found growing as emergents in five of the six cold springs studied as well as in the Avonhead Springs outflow. Nasturtium spp. were also found growing entirely submerged in three of the six cold springs studied and reached a depth of 6.5 m in Waikoropupu

Springs. The submerged growth form of Nasturtium spp. was mentioned by Fassett (1940) and Mason (1970).

In torrential and swiftly flowing waters in temperate latitudes, a substrate of bedrock, boulders and stones restricts the flora to algae, lichens and bryophytes (Sculthorpe 1967) as was found in Waikoropupu Springs and Hamurana Springs. A lower water velocity and an increase in finer substrates permit dissected-leaved vascular plants e.g. Myriophyllum spp. to become established, while on even finer substrates, broad-leaved plants e.g. linear-leaved Potamogeton spp. appear (Sculthorpe 1967). Dissected and broad-leaved species of angiosperm occurred in all the cold springs in the present study except Three Springs and the Spring at Lake Hayes where the water was very shallow.

Although substrate seems to affect the overall distribution of plants in the New Zealand cold springs, water velocity and light intensity may affect local distributions of plants on a particular substrate. The distribution of some bryophytes in Waikoropupu Springs may be limited by water velocity as a substrate of boulders is covered by the moss Cratoneuropsis relaxa where the water velocity is moderate but is covered by liverwort (Lophocolea spp.) where the water velocity is strong to very strong. Of all the cold springs studied, areas of strong water velocity were colonised by angiosperms only in Waikoropupu Springs and then only by Myriophyllum elatinoides whose dissected leaves offer little resistance to the current. Submerged broad-leaved angiosperms e.g. Nasturtium spp. and Potamogeton spp. occurred in areas of moderate water velocity in many of the cold springs studied. The effect of substrate and water velocity on the vegetation of cold springs is further considered in the General Discussion.

Light energy within the photosynthetic waveband at the bottom of Waikoropupu Springs in full sunlight was between 33% (mid-winter) and 40% (mid-summer) of the light energy in air. Bryophytes and angiosperms at the bottom of Waikoropupu Springs are unlikely to be near the limits of their vertical distribution in terms of light energy as mosses have been reported from depths as great as 18 to 20 m in Crystal Lake, Wisconsin (Juday 1934). "Shade" conditions for aquatic vascular plants are about 1% of summer daylight (Spence and Chrystal 1970) and vascular plants are normally confined to water above the depth of their compensation point, which is at about 10-15 m in a clear lake (Schomer 1934).

Biomass of bryophytes and angiosperms submerged in Waikoropupu Springs was high compared with that in other temperate waters (Sculthorpe 1967). Few comparisons with other New Zealand localities can be made, but in a North Island lake, Rotoiti, a dry weight of about 1000 g/m^2 of *Lagarosiphon major* was recorded (data of Fish 1963 calculated by Sculthorpe 1967) and in a South Island lake, also called Rotoiti, the dry weight of *Elodea canadensis* reached at least 997 g/m^2 (Taylor 1971 unpublished). Both values are lower than some recorded in Waikoropupu Springs. In the sub-tropical Silver Springs, Odum (1957a) recorded a mean dry weight of only 612 g/m^2 for the submerged eel-grass *Sagittaria lorata* (excluding *aufwuchs*). Values for plants around the edges of Silver Springs were generally higher (e.g. *Najas guadalupensis* 1950 g/m^2, *Pontederia cordata* 980 g/m^2) and more comparable to values for emergent *Nasturtium microphyllum* at Waikoropupu Springs. However, measurements of biomass should be interpreted with caution as the biomass may include several years' growth and, if expressed as dry weight, may include some inorganic matter.

Net production of free-floating Nasturtium microphyllum at Waikoropupu Springs was estimated from changes in biomass over most of the growing season. Values obtained of between 11 and 16 m.t/ha dry weight are higher than those recorded for annual production of submerged macrophytes in temperate flowing waters, e.g. 1 to 6 m.t/ha (Sculthorpe 1967). However the production of N. microphyllum in the Springs was lower than the 11 to 33 m.t/ha recorded, using similar methods, for the free-floating Eichhornia crassipes in a tropical climate (Penfound and Earle 1948; Dymond 1949, cited by Sculthorpe 1967).

In constant temperature springs, an increase in algal biomass often occurs during summer (Present study; Whitford 1956; Teal 1957). Such changes in algal biomass may be due to seasonal changes in the light climate. However, seasonal changes in algae in cold springs near Bristol, U.K. were related to changes in water discharge (Eaton 1967 unpublished, cited by Round 1968). This is unlikely to be the case in Waikoropupu Springs as there is no distinct season of maximum rainfall in the Takaka Valley (Part 1) and hence no distinct season of maximum water discharge at the Springs.

An aufwuchs community at Silver Springs (28°N latitude) persisted throughout the year (Whitford 1956) whereas the same algae (Synedra ulna and Achnanthes sp.) were present in Waikoropupu Springs (41°S) only in summer, when daily radiation was three times that in winter. Seasonal changes in algal biomass in icelandic hot springs (63-66°N) are very marked and have been attributed to seasonal changes in daily radiation which is about 50 times higher in summer than winter (Tuxen 1944).

It appears from these results that seasonal changes in algae in constant temperature springs become more marked with increasing latitude, indicating the importance of light.

PART 3

FAUNA

INTRODUCTION

The only published account of the fauna of cold springs in New Zealand is that of Marshall (1973) who studied the Avonhead Springs, Christchurch. Several studies have recorded the species of animals found in cold springs in other places including Germany (Thienemann 1912, 1926, 1931, 1950 p.85), Austria (Kühn 1940), Denmark (Nielsen 1942, 1950a,b; Thorup 1963) and North America (Noel 1954; Sloan 1956; Odum 1957a; Teal 1957; Tilly 1968; Wilhm 1970).

Several kinds of animal are recognisable in the faunas of cold springs:

(a) the "phreatic" or "groundwater" animals, generally washed from underground waters into springs (Thienemann 1912; Vandel 1920)

(b) "glacial relicts", described by Bornhauser (1913) and Nielsen (1950a,b); species restricted in distribution probably as a result of Pleistocene glaciations

(c) animals of wet soil (Thienemann 1912; Demel 1923; Kühn 1940)

(d) a common spring fauna of cold stenotherms described by Thienemann (1912, 1926, 1950) for Germany, Kühn (1940) for Austria and Pennak (1953) for North America

(e) animals usually found in other running waters (Nielsen 1950a).

One aim of the present study was to determine which of these types of animals were represented in the cold springs of New Zealand.

Many springs contain water that is constantly moving and thus show similarities with streams and rivers. In running waters, one of the major factors controlling the distribution and abundance of animals is the nature of the substrate (Hynes 1970) and many studies have related the type and density of invertebrates to substrate type (e.g. Percival and Whitehead 1929; Berg 1948; Minckley 1963; Thorup 1966; Minshall 1968). In general, the invertebrate fauna is relatively diverse on large stones but decreases in diversity and biomass as the substrate particle size decreases to that of sand. Biomass increases again as the substrate particle size further decreases to that of silt and mud (Hynes 1970). Aquatic plants provide additional substrate types for invertebrates and influence their distribution; areas with higher plants frequently being more heavily colonised by invertebrates than areas without them (Percival and Whitehead 1929; Berg 1948; Minckley 1963; Lillehammer 1966). Different species of plants may support different species of invertebrates, even in the same body of water e.g. at the spring source of Doe Run, Kentucky (Minckley 1963) or in the Danish springs studied by Thorup (1966).

Water velocity is another important factor influencing the distribution and abundance of aquatic invertebrates in streams and rivers (Berg 1948; Scott 1958; Lillehammer 1966) and one which varied considerably within the present study area. Distribution of invertebrates can also be affected by water temperature, water hardness and the level of dissolved oxygen (Berg 1948; Lillehammer 1966); but these three factors were essentially uniform throughout the Springs study area.

Several investigations have been made of the animal communities within cold springs. Silver Springs, with its extensive areas of _Sagittaria lorata_, associated _aufwuchs_ and other invertebrates contained a single plant and animal community (Odum 1957a). In the smaller Cone Spring, seven common species of invertebrates were uniformly distributed (Tilly 1968) and the spring contained a single animal assemblage. By comparison, the three cold springs studied by Thorup (1966) (Lille Blaakilde, Ravnkilde and Rold Kilde) each contained a variety of animal assemblages associated with different substrates. The distribution of invertebrate species in Waikoropupu Springs was investigated using the methods of Berg (1948) and Thorup (1966) to determine whether different animal assemblages were associated with different substrates and water velocities.

Some early investigators (Bornhauser 1913; Brehm 1930 cited by Thorup 1963) considered that because of the constant temperature of cold springs all stages in the life histories of the animals in them should be present at all times of the year. These life histories have been termed non-seasonal, in contrast to seasonal life histories in which there is a distinct change in the size distribution in the population of a species throughout the year (Hynes 1961, 1970). However, studies of cold springs have shown that the life histories of many species are seasonal e.g. in the Order Trichoptera (Demel 1923; Nielsen 1942; Thorup 1963; Gower 1965, 1967) and in other aquatic insect orders (Demel 1923; Thienemann 1925; Thorup 1963). Nonetheless, the life history of Crenobia alpina (Tricladida) in a cold spring in Lake Wigry, Poland, is non-seasonal (Demel 1923) as are the life histories of two species of Plecoptera in cold springs in Sweden (Brinck 1949) and an isopod and an ancylid in cold springs in Denmark (Thorup 1963). Another aim of the present study was to determine whether there were seasonal changes in the size distributions of some of the common species of invertebrates in Waikoropupu Springs.

PLATE 3.1: Sampling the moss community at site 1 using a Wisconsin trap. Photo: G.C. Wells

METHODS

Preliminary studies were carried out at Waikoropupu Springs from January to October 1970, followed by regular sampling visits generally every four weeks from October 1970 to February 1972, with additional visits. Five other cold springs in New Zealand (Fig. GI.1) were visited during 1970-72 and collections for identification of the species present were made from a variety of substrates using the methods outlined for Waikoropupu Springs.

COLLECTION AND SORTING OF SAMPLES

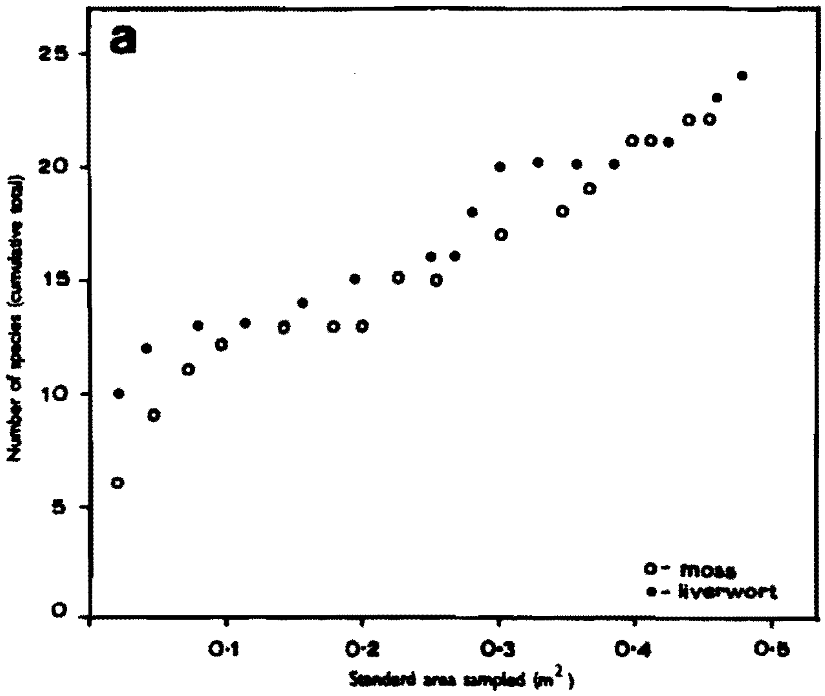
Every four weeks at Waikoropupu Springs, samples were taken of the major substrates and associated plants in water less than 1 m deep. These were boulders covered in moss (Cratoneuropsis relaxa); boulders covered predominantly in liverwort (Lophocolea spp., Neesioscyphus phoenicorhizus and Cyathophorum bulbosum); and watercress (Nasturtium microphyllum) with some silt. Between October 1970 and February 1972, 17 moss and 17 liverwort samples were taken at sites 1 and 4 (Fig. 2.1). Each sample consisted of one boulder which was collected in a Wisconsin trap with a mesh aperture of 0.42 mm. The standard area of the boulder was calculated (see Part 2). Forty-nine samples of watercress were taken between September 1970 and December 1971 at site 7, using a Hess sampler with mesh aperture 0.42 mm (see Part 2).

At about three-monthly intervals between October 1970 and February 1972, samples of other substrates and associated plants were also collected, as described in Part 2, at the sites indicated on Fig. 2.1: Cratoneuropsis relaxa at depth 4.3 m (site 2), Juncus microcephalus at depth 0.5 m (site 5), Myriophyllum elatinoides at depth 2.5 m (site 6) and Nasturtium microphyllum at depths 2.5 m (site 8) and 6.5 m (site 9). Boulders without bryophytes or angiosperms in water 0.5 m deep (site 10) were collected into a Wisconsin trap and their standard areas were calculated. While the observer was underwater on 11 March 1971, numbers of the gastropod Potamopyrgus antipodarum on a substrate of unstable sand and gravel without bryophytes or angiosperms were counted in 13 quadrats (10 x 10 cm).

Each sample was sorted live within 24 hours of collection. Animals were washed from the plants into a series of three sieves of mesh size 0.42, 0.90 and 1.5 mm and were sorted into taxonomic groups. After about 1½ hours of sorting, plant fragments and any remaining animals were preserved together in 70% ethanol. Later, all animals were sorted to species under a microscope at low magnification and were counted. Because Potamopyrgus antipodarum was often present in large numbers, a conversion factor was determined to convert dry weight per sample of P. antipodarum at a given site to numbers of animals per sample with sufficient accuracy to determine an index of abundance. To obtain this factor, 10 random subsamples of about 50 dried P. antipodarum from each of sites 1, 4 and 7 were weighed and counted.

ADDITIONAL FIELD STUDIES

Species of birds feeding in the Springs were recorded and the number of eels and trout seen while SCUBA- or snorkel-diving was also noted. In addition, egg masses and invertebrates for laboratory rearing and subsequent identification were collected and placed in plastic containers with 100 ml of Springs water. Final instar exuviae of mayflies and stoneflies were collected from the concrete stand (Site 3) about 50 cm above



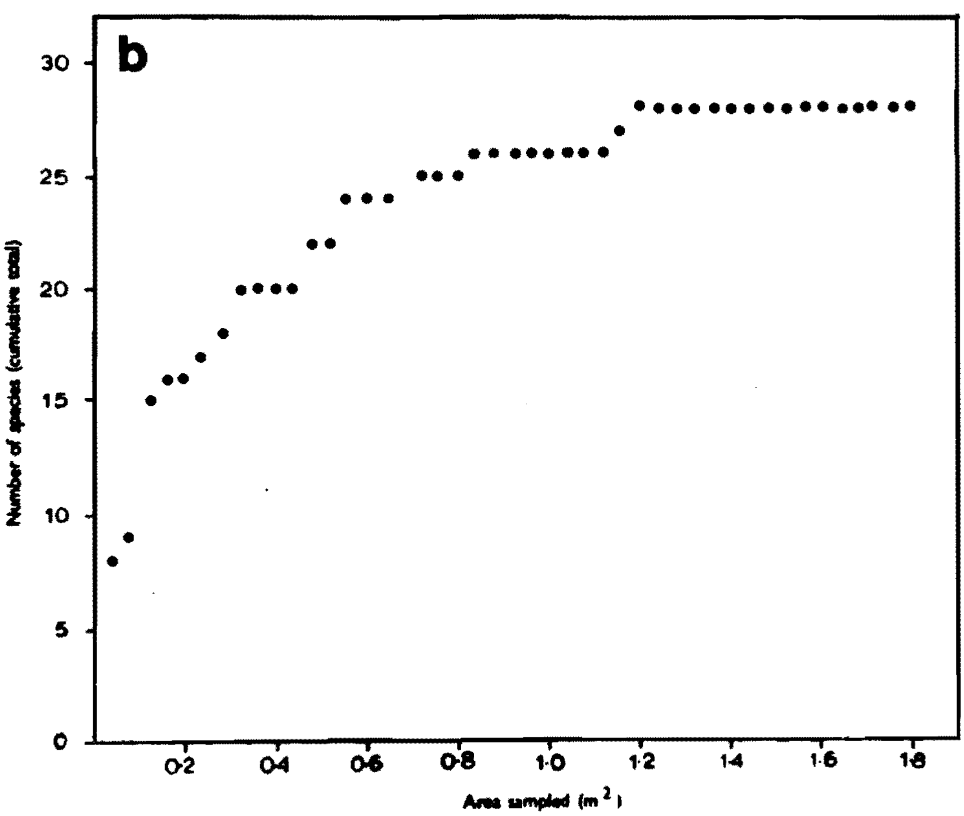


FIG. 3.1: Effect of area sampled on number of species of invertebrates recorded at three sites in Waikoropupu Springs.

a. Site 1 (moss) and site 4 (liverwort)

b. Site 7 (watercress)

water level. Whenever possible, adult insects were taken by sweep netting during the day and at dusk around the edge of the Springs.

INDICES OF ABUNDANCE

To compare the numerical abundance of species at different sites, the mean number of each species at each site over 12 months was determined. Between 3 and 34 samples (of approximate area 250 cm^2) were used in calculations for each sampling site. To avoid spurious accuracy in comparisons, the mean number was converted to an index of abundance using a logarithmic scale (Cassie 1973 unpublished):

index	number of animals/m^2
1	1 - 9
2	10 - 99
3	100 - 999
4	1000 - 9999
5	10000 - 99999
6	100000 - 999999

That is, a species present with an abundance index of 4 is about ten times more abundant than a species present with an abundance index of 3.

A simple procedure was adopted to find out whether a sufficient number of samples had been taken to reliably determine abundance indices. The cumulative number of species collected in four-weekly samples at sites 1, 4 and 7 was related to the area sampled, as suggested by Cain (1938) (Fig. 3.1a,b). Single samples at sites 1 and 4 were sufficient to recover 6-13 and 7-11 species respectively; the number of species recovered depending on the time of year. By the end of the study, about 0.5 m^2 had been sampled at these sites but the curve shown in Fig. 3.1a suggests that there may be further species with an abundance index less than or equal to 1 not collected. At site 7, three samples, each of 0.04 m^2, taken on 19 September 1970, recovered 15 species of animal. By the end of the study, 1.2 m^2 had been sampled (Fig. 3.1b) and most species present with an abundance index of 1 had been recorded. One limitation of this method, which was originally devised for terrestrial vegetation, is that it assumes that all species are present and able to be collected at all times of the year. This is often not the case when aquatic insects with aerial stages are involved.

No attempt was made to assess the reliability of the abundance indices of fauna at the other sites because of the small area which had been sampled at each site by the end of the study.

SIZE DISTRIBUTIONS OF POPULATIONS OF THE MORE ABUNDANT SPECIES

The size distributions of 11 species of invertebrates in the Springs, collected in four-weekly samples, were investigated. Generally, results from all sites sampled on a given date were combined to provide as large a sample as possible but this ignored the problem that size distributions may vary from site to site within a spring (Thorup 1971) or river (Lillehammer 1966). Almost all specimens of every sample were measured except for Potamopyrgus antipodarum, when sub-samples were measured. These sub-samples were obtained by a method similar to that described by Hynes (1961).

The measurements taken of each species are summarised in Table 3.1. Whenever possible a rigid structure was selected for measurement as whole animals may shrink when preserved (Leonard 1939). The length of the carapace of crayfish and shrimps was measured from the posterior edge of the eye-socket

TABLE 3.1: Measurement taken for estimation of size and the method and magnification used.

Species	Measurement taken	Magnification	Method
<u>Paracalliope karitane</u>	length	x 10	graduated eyepiece
<u>Paratya curvirostris</u>	carapace length	x 1	vernier callipers
<u>Paranephrops planifrons</u>	carapace length	x 1	vernier callipers
<u>Megaleptoperla diminuta</u>	headwidth	x 25	micrometer eyepiece
	length of pronotum	x 25	micrometer eyepiece
	length of wingpads	x 25	micrometer eyepiece
<u>Conuxia gunni</u>	headwidth	x 50	micrometer eyepiece
<u>Polyplectropus puerilis</u>	headwidth	x 25	micrometer eyepiece
<u>Psilochorema tautoru</u>	headwidth	x 25	micrometer eyepiece
<u>Rakiura vernale</u>	headwidth	x 25	micrometer eyepiece
<u>Zelolessica cheira</u>	headwidth	x 50	micrometer eyepiece
<u>Lymnaea columella</u>	height of shell	x 1	vernier callipers
<u>Potamopyrgus antipodarum</u>	height of shell	x 10	graduated eyepiece

to the mid-dorsal posterior border of the carapace. Insect headwidths were measured across the widest part of the head capsule. For the stonefly Megaleptoperla diminuta, additional measurements were made for instar determination: the length of the pronotum in the mid-dorsal line was recorded for about 170 specimens selected at random, and where wing pads had developed, their length was determined.

Crustacea, Plecoptera and Mollusca were grouped into size classes varying in extent from 0.1 to 1.0 mm, depending on the smallest unit in which measurements were recorded. Species of Trichoptera were grouped into instars (see below).

LABORATORY REARING

Two refrigerators maintained at 12°C ± 1C° were each fitted with two 14 watt fluorescent tubes, giving a light intensity of about 1700 lux, which is 2% of the Nelson light intensity at noon in mid-summer and 6% of that in mid-winter (see Part 1). The refrigerators were maintained at a number of different daylengths e.g. L/D = 8/16 (8 hours light followed by 16 hours dark), L/D = 12/12 and L/D = 16/8, but few experiments on the effect of the light regime on the duration of different developmental stages were undertaken.

Insect and mollusc eggs for identification were collected from the Springs and were placed in solid watch glasses (4 x 4 x 1.5 cm) with non-aerated Springs water at 12°C and with a cover of polythene to prevent evaporation. Decaying moss and watercress were added when the eggs hatched.

Adult insects were reared from larvae and pupae to permit identification. Larvae were maintained in covered plastic petri dishes (diameter 9 cm) or plastic pottles (diameter 7 cm, depth 6 cm) in which the water was not aerated, or in glass dishes (diameter 15 cm) which were aerated. Springs water, sand and stones were added as well as fresh moss and epiphytic algae (for Trichoptera and Chironomidae), decayed watercress leaves (for Plecoptera) or diatoms (for Ephemeroptera). Trichopteran pupae were reared by placing pupal cases in muslin bags attached to the side of an aquarium containing aerated Springs water. The water level reached halfway up the bag so that the pupal case was submerged, but the newly-emerged adult could crawl out into the air (method of A. G. McFarlane, pers. comm.). Adult Trichoptera were maintained in an oviposition aquarium as described by Bjarnov and Thorup (1970).

DETERMINATION OF INSTARS IN LARVAL INSECTS

(a) Plecoptera (*Megaleptoperla diminuta*)

The mean headwidth of first instar larvae (found in eggs dissected from an adult female) was known but later instars could not be determined by inspection of histograms of headwidth size classes. Therefore, Brooks' (or Dyar's) Rule (Brooks 1886; Dyar 1890, see Crosby 1973) was applied to estimate the number of instars. The Rule states that the headwidth of one instar divided by the headwidth of the preceding instar produces a constant, k_x (the quotient at ecdysis). Values for k_x for *M. diminuta* were obtained for both late and middle instar larvae, as follows.

For larvae collected in field samples, a plot of headwidth versus wingpad length separated final (F) instar larvae from penultimate (F-1) instar larvae and enabled the mean headwidth of F and F-1 instar larvae, and therefore k_x, to be calculated.

In the laboratory, larvae of middle instars were reared at 12°C to determine k_x. As the head capsule is split longitudinally at each ecdysis, headwidth measurements could not be made. Instead, the length of the pronotum of the cast skin and of the preserved ecdysed specimen was measured. Values for k_x (in the laboratory) were calculated from measurements of y_1 and y_2 using the formula:

$$k_x = \frac{y_2 + 0.21}{y_1 + 0.21}$$

where y_1 is the pronotum length prior to ecdysis

y_2 is the pronotum length after ecdysis

See Appendix 6 for derivation of this formula.

(b) Trichoptera

Measurements made on larvae obtained in field samples and on those hatched from eggs in the laboratory were combined. For each species, the number of larvae in each headwidth size class was plotted to determine the probable number of instars. Mean headwidth of each instar was calculated and the range of headwidths for each instar was determined by inspection. The quotient at ecdysis (i.e. the mean headwidth of one instar divided by the mean headwidth of the preceding instar) was calculated whenever possible.

RESULTS AND DISCUSSION
SPECIES PRESENT

A. WAIKOROPUPU SPRINGS

The aquatic animals found in the Springs during the study are listed in Table 3.2. No attempt was made to identify Protozoa.

TABLE 3.2: Species of aquatic animals collected in Waikoropupu Springs and five other New Zealand cold springs (excluding spring outflows) on the sampling dates indicated. Introduced species are marked by an asterisk.

Species	SOUTH ISLAND			NORTH ISLAND		
	Waikoropupu Springs	Spring at Lake Hayes	Three Springs	Otangeroa Springs	Hamurana Springs	Western Springs
PLATYHELMINTHES						
Temnocephala novaezelandiae	x					
Cura pinguis	x					
Dugesia n.sp.1?			x			
Dugesia n.sp.2	x					
ROTIFERA						
? *Lecane* sp.	x					
Flosculanidae (1 genus)	x					
NEMATODA						
Dorylaiminae (2 genera)	x					
Chromadoridae (1 genus)	x					
ANNELIDA						
Haplotaxidae	x					
* *Lumbriculus variegatus*	x					
Oligochaeta (unid.)		x				
ARTHROPODA						
Tardigrada (1 genus)	x					
Crustacea						
Herpetocypris pascheri	x					
Other ostracods		x				
Copepoda	x					
Amphipoda						
Paracalliope karitane	x					
Paraleptamphopus subterraneus				x		
Paraleptamphopus n.sp.?	x		x			
Decapoda						
Paratya curvirostris	x					x
Paranephrops planifrons	x			x	x	x
Acarina						
Tryssaturus n.sp.?	x					
Zelandobates n.sp.	x					
Insecta						
Odonata						
Xanthocnemis zealandica	x			x	x	
Ephemeroptera						
Deleatidium myzobranchia	x					
Deleatidium sp.			x			
Zephlebia dentata						x

TABLE 3.2 (cont'd.)

Species	Waikoropupu Springs	Spring at Lake Hayes	Three Springs	Otangeroa Springs	Hamurana Springs	Western Springs
Zephlebia scita‡‡	x					
Zephlebia versicolor				x	x	
Plecoptera						
Megaleptoperla diminuta	x					
Stenoperla prasina			x			
Zelandobius furcillatus?					x	
Plecoptera (unid.)		x			x	
Coleoptera						
Hydora sp.	x					
Diptera						
Chironomidae (unid.)		x			x	
Chironomus zealandicus	x	x				
Maoridiamesa harrisi			x			
Orthocladiinae	x					
Ephydridae (1 species)	x					
Limnophora sp.	x					
Stratiomyidae	x					
Limonia sp.	x					
Trichoptera						
Helicophidae						
Zelolessica cheira	x					
Helicopsychidae						
Helicopsyche poutini	x					
Rakiura vernale	x					
Hydroptilidae						
Oxyethira n.sp.	x					
Oxyethira spp.			x		x	
Hydroptilidae (unid.)				x		
Leptoceridae						
Hudsonema amabilis	x					x
Triplectides obsoleta					x	
Polycentropodidae						
Polyplectropus puerilis	x					
Rhyacophilidae						
Hydrobiosis parumbripennis	x		x		x	
Hydrobiosis n.sp.?	x					
Psilochorema tautoru	x					
Psilochorema bidens?		x			x	
Sericostomatidae						
Conuxia gunni	x					
Oeconesus sp.			x			
Olinga feredayi					x	
Pycnocentria evecta			x		x	
Pycnocentrodes sp.			x			
Other sericostomatids		x				
Lepidoptera						
Nymphula nitens		x				

TABLE 3.2 (cont'd.)

Species	Waikoropupu Springs	Spring at Lake Hayes	Three Springs	Otangeroa Springs	Hamurana Springs	Western Springs
MOLLUSCA						
**Lymnaea columella*	x					x
(**Physa* and/or *Physastra*				x		
Potamopyrgus antipodarum	x	x	x	x	x	x
Sphaerium novaezelandiae	x	x			x	
PISCES						
Anguilla australis schmidtii	x					
Anguilla dieffenbachii	x					
Anguillidae (unid.)				x		
* *Salmo trutta*	x					
* *Salmo gairdneri*					x	
Philypnodon breviceps†	x					
TOTAL NUMBER OF SPECIES COLLECTED about	46	10	11	10	15	6

REFERENCE: Waikoropupu Springs, Jan 1970-Feb 1972; Spring at Lake Hayes, 21 Feb 1971; Three Springs, 15 Feb 1971, 31 Oct 1972; Otangeroa Springs, 16 Feb 1972; Hamurana Springs, 24 Aug 1970, 5 May 1971; Western Springs, 28 Aug 1970 and Zoology Dept. Auckland University (1962 unpub.), Johnstone (1972), Pullan *et al* (1972).

‡ *Zephlebia scita* (Walker) = *Zephlebia nodularis* (Eaton). This synonomy is based on Penniket (1961) and J. G. Penniket (unpublished key to N.Z. Ephemeroptera).

† Single specimen taken in study area during study period.

Note: *Zelandoperla agnetis* (Plecoptera) was recorded from Pupu Springs by McLellan (1967) but the locality should have been reported as Fish Creek near the footbridge (D.A. Craig, pers. comm.), where this species was also taken in the present study.

Of the 46 aquatic species recorded, nearly half belong to the Insecta (21 spp.) and these include 10 species of Trichoptera. Other aquatic species belong mainly to the Platyhelminthes (3 spp.), Crustacea (6 spp.), Mollusca (3 spp.) and Pisces (4 spp.). Three species have been introduced to New Zealand: the oligochaete Lumbriculus variegatus (Brinkhurst 1971); the snail Lymnaea columella (Pullan 1969), and the trout Salmo trutta (Thompson 1922).

There have been few collections of freshwater invertebrates from North-West Nelson and several species found in Waikoropupu Springs are undescribed. These include a new genus of Orthocladiinae and probable new species of Dugesia (Tricladida), Tryssaturus and Zelandobates (Acarina) and Hydrobiosis and Oxyethira (Trichoptera). A species of Trichoptera, Rakiura vernale McFarlane, 1973 was recently described from Waikoropupu Springs as a result of the collection of adults during the present study (see Part 4).

Semi-aquatic and terrestrial animals taken within the shoreline of the Springs are listed in Table 3.3a,b. All were taken around the extreme edge of the Main Spring. Aerial stages of several aquatic insects, the larvae of which were not found in the Springs during the study, were taken by sweep netting around the Springs (Table 3.3c). The larvae of these species presumably occur in nearby waters such as Fish Creek, the Springs outflow or the Waikoropupu River.

Seven species of native birds from six families were seen feeding in or around the Springs (Table 3.3d). Several of these are commonly associated with aquatic habitats: Phalacrocorax melanoleucos (little shag) and Anas superciliosa (grey duck) with fresh water, Porphyrio porphyrio (pukeko) with swamps and Ardea novaehollandiae (white faced heron) with the sea coast. The other species are usually associated with the

TABLE 3.3: Species of animals at Waikoropupu Springs (excluding Springs outflow), except for species recorded in Table 3.2. Introduced species are marked by an asterisk.

a. Semi-aquatic (damp ground)

Insecta
  Diptera
    Zelandotipula sp.

b. Non aquatic (species taken within the Springs shoreline on more than one occasion, but no stage of life history spent submerged in water)

Insecta
  Lepidoptera
    **Pieris rapae* (Linnaeus) (adult)
  Hemiptera
    Microvelia macgregori (Kirkaldy)
Arachnida
    Dolomedes n.sp.?
MOLLUSCA
    Agriolimax agrestis (Linnaeus)

c. Adults of aquatic insects collected around the Springs, the larvae of which were not found in the Springs.

Diptera
  Polypedilum opimus (Hutton)
  Austrosimulium ungulatum Tonnoir
  Austrosimulium australense Tonnoir
Odonata
  Lestes colensonis (White)
Trichoptera
  Beraeoptera roria Mosely
  Hydropsyche colonica McLachlan
  Hydropsyche raruraru McFarlane
  Neurochorema confusum McLachlan
  Pycnocentria hawdonia McFarlane
  "Triplectides" sp.

d. Birds feeding in or around the Springs

Anas superciliosa Gmelin (Anatidae)
Ardea novaehollandiae (Latham) (Ardeidae)
Gallirallus australis (Sparrman) (Rallidae)
Halcyon sancta Vigors et Horsfield (Alcedinidae)
Phalacrocorax melanoleucos (Vieillot) (Phalacrocracidae)
Porphyrio porphyrio (Linnaeus) (Rallidae)
Rhipidura fuliginosa Sparrman (Muscicapidae)

edge of forests: Gallirallus australis (weka), Halcyon sancta (kingfisher) and Rhipidura fuliginosa (pied fantail) (Falla, Sibson and Turbott 1966). On several occasions cattle were seen grazing within the shoreline of the Springs.

B. OTHER COLD SPRINGS IN NEW ZEALAND

The animals collected from the other cold springs shown in Fig. GI.1 are also listed in Table 3.2. The number of species collected at each spring reflects not only the number of species present but also the intensity of collection and the time of year when collections were made. The largest number of aquatic species was collected from Waikoropupu Springs with fewer species from Hamurana Springs, Three Springs, the spring at Lake Hayes, Otangeroa Springs and Western Springs (inflow).

The fauna of the other five cold springs was similar to that of Waikoropupu Springs, including Planaria; Amphipoda; Decapoda; larvae of Odonata, Ephemeroptera, Plecoptera, Chironomidae and Trichoptera; and Gastropoda. The only species found in every cold spring studied was the widely distributed Potamopyrgus antipodarum (Gastropoda) but other species found in at least three of the six springs were Paranephrops planifrons (Decapoda), Xanthocnemis zealandica (Odonata) and Hydrobiosis parumbripennis (Trichoptera). The genera Zephlebia (Ephemeroptera), Oxyethira and Psilochorema (Trichoptera) were common to at least three of the springs. The vertebrate fauna included Anguilla spp. and Salmo spp. The species introduced to New Zealand have been mentioned above with the exception of the rainbow trout Salmo gairdneri (Thompson 1922) which occurred in Hamurana Springs.

There are some interesting features of the distribution of the invertebrates found in these New Zealand cold springs. Many of the common animals found belong to genera that are endemic to New Zealand, e.g. Paranephrops (Hopkins 1970b); Zephlebia, Megaleptoperla, Conuxia, Psilochorema, Hydrobiosis (I.D. McLellan, pers. comm); Rakiura (McFarlane 1973) and Zelolessica (the family Helicophidae to which this genus belongs is endemic to Australia and New Zealand) (Riek 1970).

Other species found in the springs belong to genera having a wider distribution but the species are endemic to New Zealand e.g. Paratya (Australia, Asia) (Bishop 1967); Dugesia (cosmopolitan) (Hyman 1951); Paracalliope (New Zealand, Australia, Phillipines, India) (Barnard 1969); Helicopsyche (cosmopolitan) (Hynes 1970); Potamopyrgus (Western Europe but probably not native, possibly Australia) (Winterbourn 1970a).

Most of the aquatic species in the cold springs are widely distributed in New Zealand, including Lumbriculus variegatus (Brinkhurst 1971), Herpetocypris pascheri (Chapman 1963), Xanthocnemis zealandica (Penniket 1966), Conuxia gunni (D.R. Cowley, A.G. McFarlane, K.A.J. Wise, unpublished records), Hydrobiosis parumbripennis (McFarlane 1951a), Zelolessica cheira (McFarlane 1964), Lymnaea columella (Pullan, Climo and Mansfield 1972) and Potamopyrgus antipodarum (Winterbourn 1970a). Other species found in Waikoropupu Springs may be confined to Nelson, Marlborough and the West Coast in the South Island and to the North Island e.g. Paranephrops planifrons (Hopkins 1970b); to Nelson and the West Coast in the South Island e.g. Helicopsyche poutini and Oxyethira n.sp. (A.G. McFarlane, pers. comm.) or may occur only rarely east of the Southern Alps e.g.

Psilochorema tautoru (A.G. McFarlane, pers. comm.).

Some species occur in cold springs far outside their normal geographic range and may be classed as relicts. Rakiura vernale (Trichoptera:Helicopsychidae), found in Waikoropupu Springs, appears to be a glacial relict and is discussed in Part 4.

Some of the animals in the cold springs studied originated from groundwater while others came from the sea. Two phreatic species were collected: a white, eyeless planarian, Dugesia n.sp., known only from Waikoropupu Springs and an amphipod, Paraleptamphopus subterraneus, from Otangeroa Springs. Paraleptamphopus subterraneus is a troglophile (May 1963), modified for a subterranean existence by loss of eyes and pigmentation. Many studies of cold springs have reported the presence of phreatic fauna, including species of Planaria (Vandel 1920; Carpenter 1928), Amphipoda (Thienemann 1912; Efford 1959); Syncarida (Efford 1959) and Isopoda (Minckley 1961).

Some species are found in the cold springs during part of their life history but spend the remainder downstream in estuaries or in the sea e.g. Paratya curvirostris (Richardson and Yaldwyn 1958) and Anguilla spp. (Cairns 1941). Paracalliope karitane (Amphipoda:Eusiridae), known only from Waikoropupu Springs and from the lower reaches of the Hutt River, Wellington, may be an estuarine species (Barnard 1972). Its salinity tolerance would be an interesting investigation in view of the sodium chloride content of water in Waikoropupu Springs (165 g/m^3), which is high for freshwater.

No species characteristic of "wet soil" were found. The reason for the absence of this type of animal, which was found in cold springs by Thienemann (1912), Demel (1923) and Kühn (1940), is not known.

Factors other than the location of the cold spring, such as water velocity, temperature and chemistry may influence the fauna. Most of the aquatic species found in the cold springs are typically found in running waters. However, where water velocities are slight, such as around some of the shoreline of Waikoropupu Springs and in parts of the Spring at Lake Hayes, there were species characteristic of "standing water" or seepages e.g. Tropocyclops prasinus, Herpetocypris pascheri (Chapman 1963) and Lymnaea columella (Pullan et al 1972). No true plankters were found in Waikoropupu Springs because of the moderate to very strong water velocities and low mean holding time of water but the presence of plankton was not investigated in the other springs.

The fauna of the New Zealand cold springs includes at least two species that are presumably cold stenotherms. Psilochorema tautoru (Trichoptera:Rhyacophilidae) is generally found over 300 m above sea level (McFarlane 1951b) but has been found in two cold springs near sea-level, Waikoropupu Springs and a spring at Hunt's Beach, Westland (A.G. McFarlane, pers. comm.). Rakiura vernale (Trichoptera:Helicopsychidae) is discussed in Part 4. Many species of stenothermous invertebrates confined to springs and springbrooks have been recorded in other parts of the world e.g. Bythinella dunkeri (Gastropoda) (Thienemann 1912), Apatidea muliebris (Trichoptera) (Nielsen 1950b) and Crenobia alpina (Tricladida) (Arnold and Macan 1969).

The feeding habits of the animals were not investigated but the species list from the New Zealand cold springs did not include any known filter feeders, probably because of the low level of particulate organic matter in the spring waters (M.E.U. Taylor, pers. comm.).

DISTRIBUTION AND ABUNDANCE OF INVERTEBRATES WITHIN WAIKOROPUPU SPRINGS

The total numbers and species composition of invertebrates varied between sampling sites (Appendices 9, 10). Many of the differences between sites can be related to substrate type and water velocity.

Underwater observations in the Springs showed that the number of invertebrates, excluding Potamopyrgus antipodarum, was greater on a substrate of boulders in a very strong water velocity than on unstable sand and gravel. Neither of these substrates was colonised by higher plants. The presence of higher plants was correlated with an increase in the total number of invertebrates, as expressed by the index of abundance (Table 3.4). A substrate of boulders and bryophytes (sites 1 and 4) had a higher abundance index than a similar substrate (at a similar depth) without bryophytes (site 10). The fauna on a substrate of gravel and angiosperms in shallow water (site 5) had an abundance index of 5 (Table 3.4) whereas the fauna was less abundant on a similar substrate that was too unstable for the growth of angiosperms (abundance index 4, Appendix 9j). The fauna was more abundant on bryophytes at site 4 than on different species of bryophytes at site 1. Differences in water velocity rather than the presence, or absence, or the specific composition of higher plants may have accounted for some of the differences in invertebrates between these sites.

Although there were differences in the total abundance of invertebrates at different sites in shallow water (less than 1 m) in Waikoropupu Springs (Table 3.4), there were few differences in the proportions of animals from each taxonomic group. At all sites in shallow water, the abundance index of *P. antipodarum* was the same as the abundance index of the total invertebrates, because *P. antipodarum* comprised between 88% and 96% of the total number of invertebrates at each site except site 10 where it comprised 56% of the total. At all sites in shallow water, except 10, the abundance indices of

Potamopyrgus antipodarum > other invertebrates (excl. insects) ⩾ insects

whereas at site 10,

Potamopyrgus antipodarum = insects > other invertebrates

(refer to Table 3.4)

Reduced numbers of *Potamopyrgus antipodarum* and other invertebrates except insects at site 10 may be related to the strong water velocities and lack of higher plants at that site.

TABLE 3.4: Numbers of *Potamopyrgus antipodarum*, insects and other invertebrates per m^2 and their abundance indices (in brackets) at nine sites in Waikoropupu Springs, arranged in order of increasing depth. e. = estimated. (Refer to Appendix 9 for raw data).

Site	Depth (m)	*P. antipodarum*	Insects	Other invertebrates	Total invertebrates
10	0.5	2,900 (4)	1500 (4)	900 (3)	5,200 (4)
5	0.5	e.25,000 (5)	370 (3)	2300 (4)	28,000 (5)
1	0.6	e.40,000 (5)	3700 (4)	1900 (4)	46,000 (5)
4	0.6	e.180,000 (6)	1800 (4)	5500 (4)	190,000 (6)
7	0-0.8	e.30,000 (5)	200 (3)	1800 (4)	32,000 (5)
6	2.5	2,500 (4)	150 (3)	1800 (4)	4,400 (4)
8	2.5	2,500 (4)	16 (2)	680 (3)	3,200 (4)
2	4.3	2,000 (4)	25 (2)	220 (3)	2,300 (4)
9	6.5	4,000 (4)	9 (1)	530 (3)	4,500 (4)

An increase in depth from 0.6 m to 6.5 m in Waikoropupu Springs coincided with a decrease in abundance of the total invertebrates (Table 3.4). (Site 10 is disregarded as it is the only sampling site without higher plants). On the same species of plant, the index of abundance decreased with increasing depth of water, e.g. animals on Nasturtium microphyllum had an index of abundance of 5 at the water surface (site 7) and 4 at depths 2.5 m and 6.5 m (sites 8 and 9) and on Cratoneuropsis relaxa, had an index of 5 at depth 0.6 m (site 1) and 4 at depth 4.3 m (site 2). One probable explanation for the ten-fold decrease in invertebrate abundance is that because of the reduced intensity and altered spectral composition of light in deeper water in the Springs, plant production is reduced and there is less food available to the invertebrates. Another explanation is that invertebrate movement into deeper water is made difficult because the direction of the water currents is upwards and outwards from the vents to the surface and edges of the Springs.

All the major invertebrates showed a decrease in abundance with an increase in depth e.g. numbers of Potamopyrgus antipodarum decreased about ten-fold (Table 3.4) as did numbers of other invertebrates excluding insects (i.e. mainly Crustacea). The decrease in numbers of insects was more marked and ranged from 100-fold to 1000-fold. The reason for the more pronounced decrease in abundance of insects compared to that of other invertebrates is uncertain. One possible explanation is that the life history of most aquatic insects at the Springs includes an aerial stage and takes only one year. Therefore the larval stage has less than a year to travel from egg-laying sites (probably in shallow water) to the deep water of the Springs and return to shallow water for pupation and emergence. Invertebrates other than insects are continually in the water and have periods of time extending over many life histories available for colonisation.

Some species of invertebrates were widespread within the Springs whereas others had restricted distributions.

Four main substrate and water velocity types had an abundant fauna and accounted for about 75% of the Springs area (types a, b, c and e, Table 3.5). Ten species of invertebrates were common (i.e. numerous or less numerous) on at least three of these four types, namely, four species of Crustacea, five species of Insecta (including three species of Trichoptera) and the ubiquitous mollusc Potamopyrgus antipodarum (Table 3.5).

Some species had restricted distributions within the Springs. Characteristic species of animals, as defined by Berg (1948) and Thorup (1966) and elaborated in the legend to Table 3.5, were found on three of the five major substrate and water velocity types in the Springs. Because the fauna of the deeper areas of the Springs was restricted both in number of species and number of individuals, Table 3.5 refers only to the fauna associated with substrate and water velocity types in shallow water. Deeper areas were considered as vertical extensions of the equivalent shallow water substrate and water velocity type.

Boulders without bryophytes, in a very strong water velocity, covered about 5% of the area of the Springs and were characterised in shallow water by the presence of Dugesia sp. (Tricladida) and Deleatidium myzobranchia (Ephemeroptera). Potamopyrgus antipodarum was numerous and four species of Trichoptera less numerous (Table 3.5a).

TABLE 3.5: Five substrate and water velocity types, and associated species of plants in shallow water in Waikoropupu Springs with their characteristic, numerous and less numerous species of animals. Characteristic species are present with an abundance index of at least 3 in the area but are present with an abundance index of usually no more than 1 in other areas. Other numerous species are present with an abundance index of at least 3 in the area; less numerous species are present with an abundance index of 2. (Refer to Appendix 10).

Characteristic species	Other numerous species	Less numerous species
a. Boulders, very strong water velocity with no higher plants.		
	(Example - site 10)	
Dugesia sp. *Deleatidium myzobranchia*	*Potamopyrgus antipodarum*	*Helicopsyche poutini* *Hydrobiosis parumbripennis* *Psilochorema tautoru* *Rakiura vernale*
b. Boulders, moderate-strong water velocity, covered in bryophytes.		
	(Example - sites 1 and 4)	
Conuxia gunni *Zelolessica cheira*	*Paracalliope karitane* *Polyplectropus puerilis* *Psilochorema tautoru* *Potamopyrgus antipodarum*	*Paraleptamphopus* sp. *Paratya curvirostris* *Paranephrops planifrons* *Megaleptoperla diminuta* *Chironomus zealandicus* Orthocladiinae *Helicopsyche poutini* *Rakiura vernale*
c. Gravel, slight to strong water velocity, with angiosperms.		
	(Example - site 5)	
none	*Paracalliope karitane* *Potamopyrgus antipodarum*	*Lumbriculus variegatus* *Paraleptamphopus* sp. *Paratya curvirostris* *Paranephrops planifrons* *Megaleptoperla diminuta* Orthocladiinae *Polyplectropus puerilis*

TABLE 3.5: continued

Characteristic species	Other numerous species	Less numerous species
		Psilochorema tautoru Rakiura vernale Zelolessica cheira
d. Unstable sand and gravel, slight to strong water velocity with no higher plants.		
none	Potamopyrgus antipodarum	none
e. Silt or water of slight velocity, with free-floating watercress. (Example - site 7)		
Lumbriculus variegatus Herpetocypris pascheri Tropocyclops prasinus Lymnaea columella	Paracalliope karitane Paraleptamphopus sp. Megaleptoperla diminuta Potamopyrgus antipodarum	Paratya curvirostris Paranephrops planifrons Xanthocnemis zealandica Stratiomyidae Chironomus zealandicus Orthocladiinae Polyplectropus puerilis Psilochorema tautoru Sphaerium novaezelandiae

Moss or liverwort growing on boulders or bedrock in a moderate to very strong water velocity comprised about 28% of the area of the Springs and included sites 1-4. The fauna at site 2 was poorly developed and that of site 3 was not investigated but the characteristic feature in shallow water (e.g. sites 1 and 4) was the presence of the Trichoptera Conuxia gunni and Zelolessica cheira. Other numerous species in this area included an amphipod, two trichopterans and Potamopyrgus antipodarum. Eight species (three crustaceans and five insects) were recorded as less numerous (Table 3.5b).

Watercress associated with silt and water of very slight velocity covered a mean area of about 19% of the Springs. Here Lumbriculus variegatus (Annelida), Herpetocypris pascheri (Ostracoda), Tropocyclops prasinus (Copepoda) and Lymnaea columella (Gastropoda) were characteristic. Watercress has been introduced to New Zealand and two of these four characteristic species of invertebrate are also introduced. Other numerous species included two amphipods, an insect and Potamopyrgus antipodarum. Nine species, mostly insects, were recorded as less numerous (Table 3.5e).

No invertebrate species were characteristic of the remaining substrate and water velocity types (types c and d, (Table 3.5). On unstable sand and gravel, Potamopyrgus antipodarum was the only numerous species recorded but on gravel with angiosperms, Paracalliope karitane was also recorded. Ten species (an annelid, three crustaceans and six insects) were recorded as less numerous on gravel with angiosperms but the fauna on unstable gravel was restricted to Potamopyrgus antipodarum.

The abundance of invertebrates within Waikoropupu Springs can be compared with that in cold springs overseas.

Underwater observations in the Springs suggested that boulders without bryophytes had similar numbers of invertebrates to unstable sand and gravel. However, Minckley (1963) at the spring source of Doe Run, Kentucky, found slightly higher numbers of invertebrates on bare riffles than on shifting sand. In Morgan's Creek, the number of invertebrates collected per unit time was three times higher on bedrock at the spring source than on rubble 25 m downstream (Minshall 1968). No other studies of cold springs have been concerned with the numbers of invertebrates on substrates that were not colonised by higher plants.

In Waikoropupu Springs, a substrate of boulders with bryophytes had a more abundant fauna than a similar substrate without bryophytes, and stable gravel with angiosperms had a more abundant fauna than unstable gravel without angiosperms. Most other studies have also shown that the presence of higher plants increases the abundance of invertebrates. At station I of Doe Run (Minckley 1963), the invertebrate fauna was much more abundant in beds of moss (Fissidens julianus) and watercress (Nasturtium officinale) than on bare riffles or shifting sand. In rivers such as the Tuel Aa at Frederikshaab (Berg 1948) a stony bottom with Elodea canadensis and various algae had a fauna that was three times more abundant than a similar substrate without plants. Lillehammer (1966) found in a Norwegian river that there was a much greater diversity of invertebrates where there was a thick moss growth than on a bare substrate. The increased numbers of invertebrates on higher plants are probably due to the shelter, food and case-building materials provided by the plants (Gaevskaya 1966). However, a study of a small spring with a mud bottom

(Wilhm 1970) showed that the "open" areas had six times more invertebrates than areas with vegetation. The reduction of the numbers of invertebrates in the vegetation was attributed to the choking effect of the plant roots.

Biomass of the invertebrates will be discussed in Part 5 and their distribution and that of the plants will be considered together in the General Discussion.

ASPECTS OF THE BIOLOGY OF THE MORE ABUNDANT SPECIES

Data on seasonal changes in size distribution were obtained for some of the more abundant species in Waikoropupu Springs. The Trichoptera and Plecoptera were of particular interest and information of their life histories is given.

INSECTA
TRICHOPTERA

The five common species (*Conuxia gunni*, *Polyplectropus puerilis*, *Psilochorema tautoru*, *Rakiura vernale* - see Part 4, and *Zelolessica cheira*) were studied in the most detail.

Eggs: The eggs of four species are described in Table 3.6. Both species of Rhyacophilids (*H. parumbripennis* and *Ps. tautoru*) generally laid a mass of 200-300 eggs in a regular array on the underside of boulders whereas the egg masses of the other two species contained fewer eggs. *Polyplectropus puerilis* laid an irregular mass on moss and *R. vernale* a spiral ribbon which was attached to the bottom of the laboratory container. All eggs collected in the Springs were in water less than 35 cm deep and underwater observations suggested that the egg-laying sites of the Trichoptera were confined to water less than 60 cm deep.

Eggs from each egg mass were at least 85% viable and

TABLE 3.6: Field and laboratory observations on the eggs of four species of Trichoptera from Waikoropupu Springs. N.D. denotes no data.

Species	Morphology of egg	No. of eggs in egg mass	Field collection: Date	Field collection: Site & depth	Laboratory rearing (12°C and L/D -12/12) Time (days) to first hatching	Laboratory rearing: last hatching
Hydrobiosis parumbripennis	white, oval, length 0.32 mm		6 Feb 1971	N.D.	4	4
		200-300	1 May 1971	near 10, 30 cm	(a) 3	3
					(b) 4	4
			20 Mar 1972	near 10, 30 cm	3	3
Psilochorema tautoru	white, oval length 0.32 mm	~100	29 Aug 1971	3	8	13
		200-300	19 Feb 1972	10	N.D.	
			20 Mar 1971	10	41	44
Polyplectropus puerilis	white, spherical, diam. 0.37 mm	~100	9 Jan 1971	3	3	3
			24 Jul 1971	25 cm	3	9
Rakiura vernale	orange, spherical, diam. 0.19 mm	~100	N.D. (eggs laid in laboratory on 27 Sep 1971)		21 (L/D-16/8)	24
					46 (L/D-8/16)	48

hatched in the laboratory at 12°C over a restricted period; the time from hatching of the first to the last egg not exceeding six days. A similar situation has been recorded in the egg development of Drusus annulatus (Trichoptera:Limnephilidae) which took 18 days at 10°C and 13-14 days under laboratory conditions at 15-20°C (Gower 1973). By contrast, an extended period of hatching of the eggs of some Plecoptera and Ephemeroptera has been inferred by Hynes (1970).

Determination of larval instars

Measurements of larval headwidth indicated the presence of five larval instars for Polyplectropus puerilis (Fig. 3.2) and Psilochorema tautoru (Fig. 3.3). The quotient at ecdysis ranged from 1.47 to 1.70 (P. puerilis) and 1.56 to 1.82 (Ps. tautoru) suggesting that no larval instars had been overlooked. Rakiura vernale appears to have five larval instars (Part 4) with a quotient at ecdysis between instars 1 and 2 of 1.67.

Measurements of larval headwidth suggested the presence of four larval instars in field collections of C. gunni (Fig. 3.4) and Z. cheira (Fig. 3.5). Groupings of larvae are tentative as very few specimens of the early instars were obtained and, in later instars, the headwidth ranges overlapped. An additional measurement, such as forefemur length, would be required to separate the later instars. The quotient at ecdysis ranged from 1.41 to 1.67 (C. gunni) and 1.50 to 1.57 (Z. cheira) suggesting that no instars had been overlooked in the size range studied. In neither case were eggs obtained and hatched.

The mean headwidth of first instar larvae of Hydrobiosis parumbripennis was 0.21 mm.

The results obtained in the present study are in

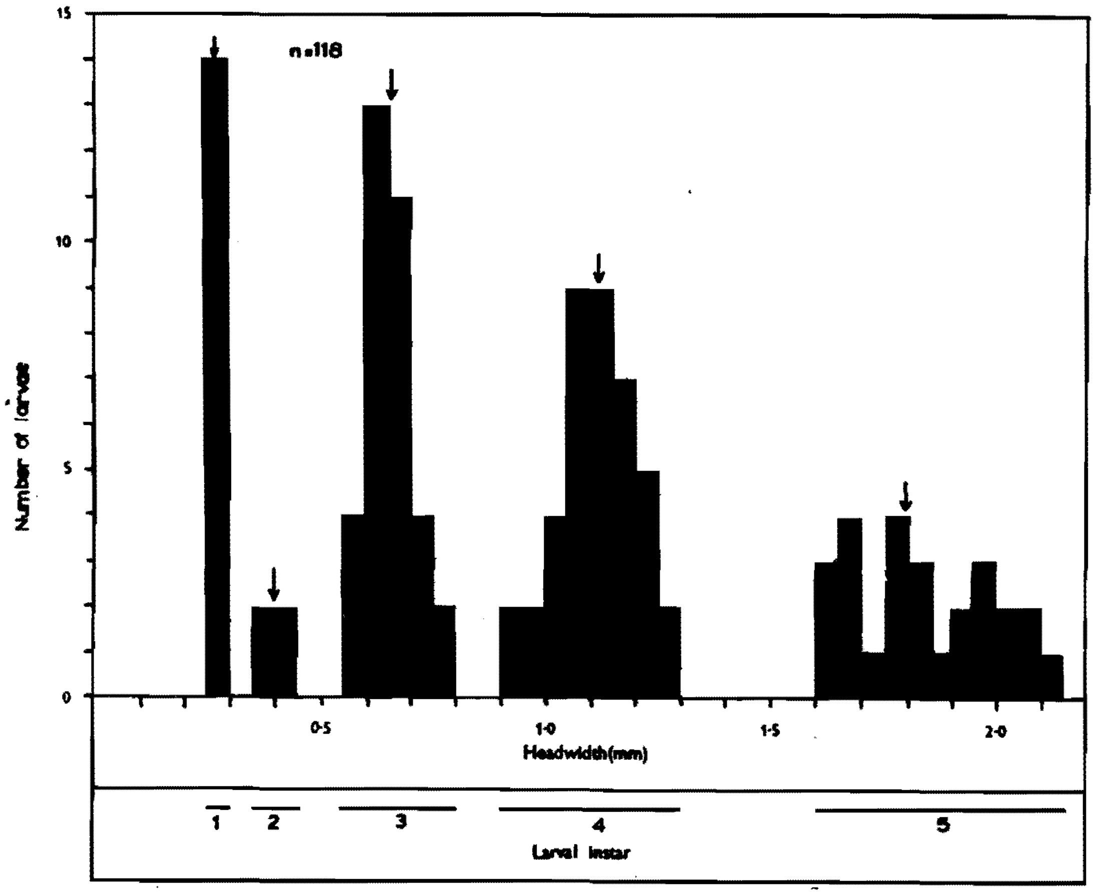


FIG. 3.2: *Polyplectropus puerilis*. Larval headwidths. Arrows indicate mean headwidths of suggested instars.

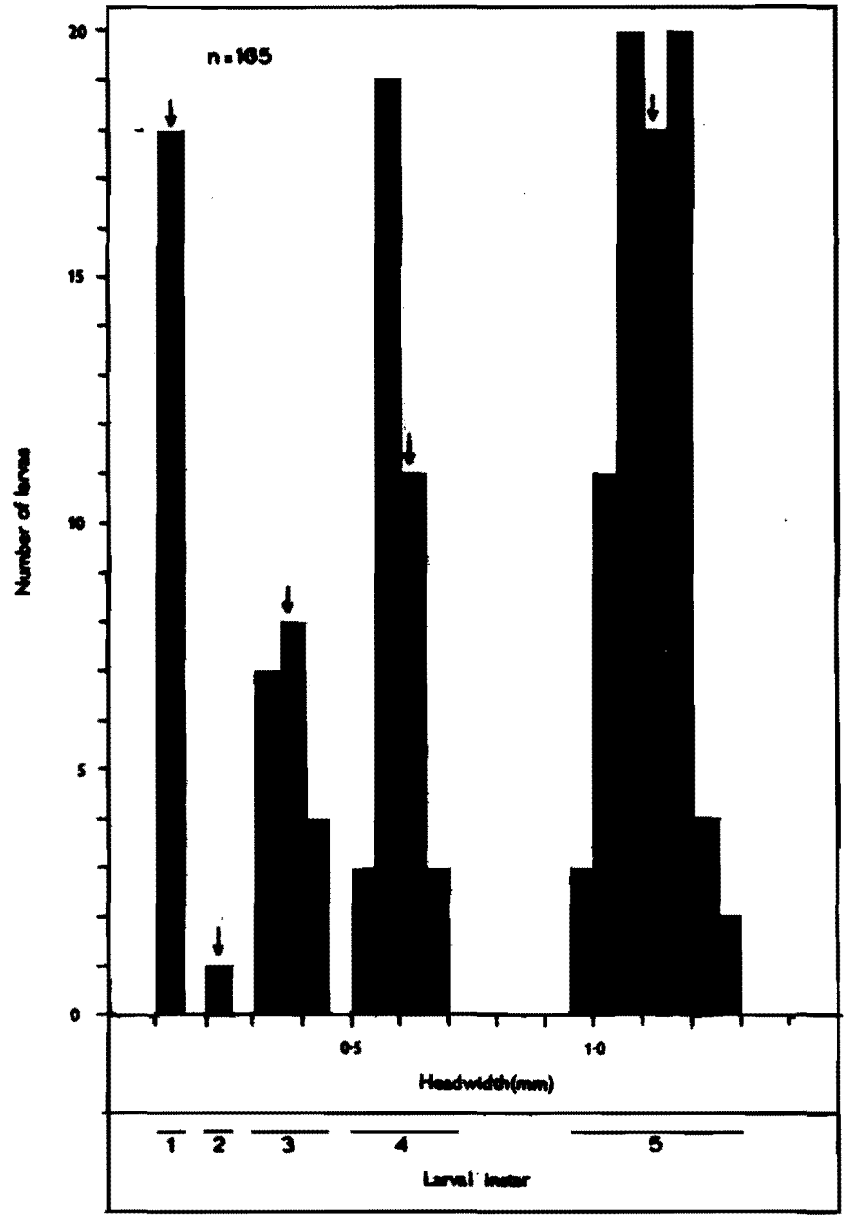


FIG. 3.3: *Psilochorema tautoru*. Larval headwidths. Arrows indicate mean headwidths of suggested instars.

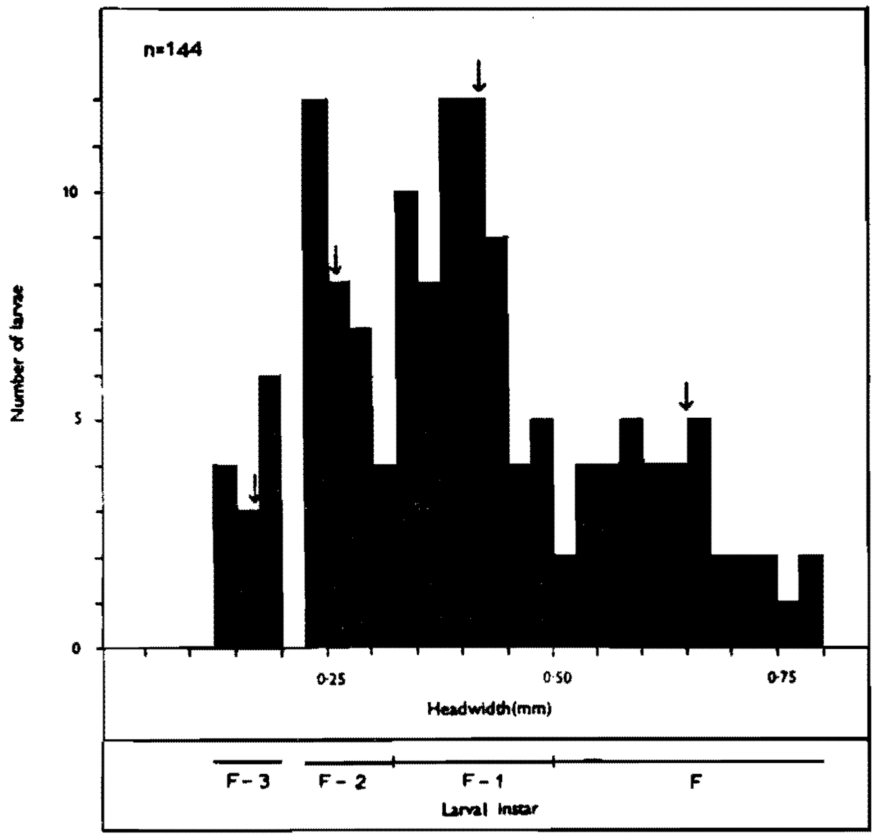


FIG. 3.4: Conuxia gunni. Larval headwidths. Arrows indicate mean headwidths of suggested instars.

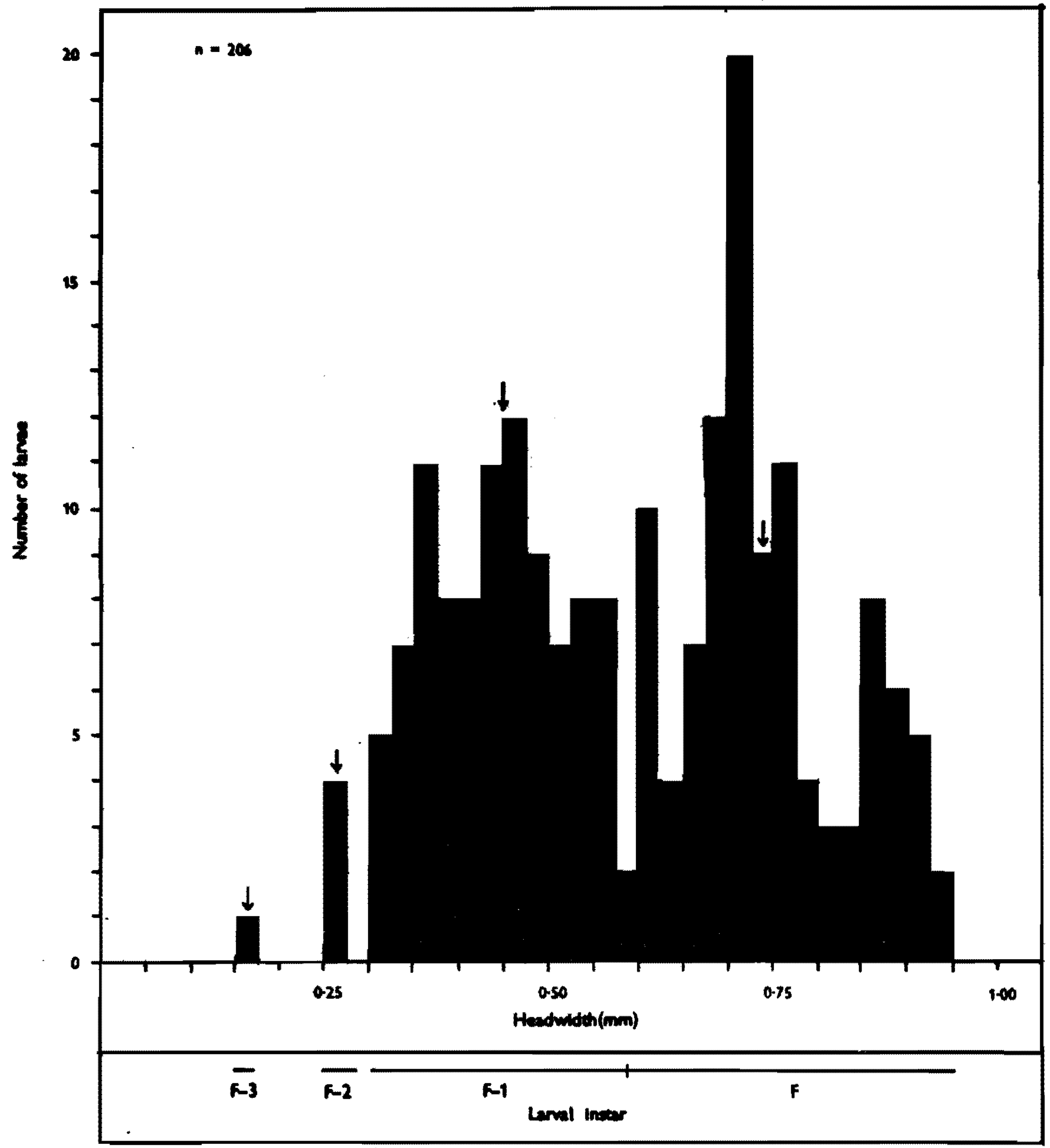


FIG. 3.5: Zelolessica cheira. Larval headwidths. Arrows indicate mean headwidths of suggested instars.

reasonable agreement with those of Nielsen (1942) who reported that the usual quotient at ecdysis is about 1.5 for Trichoptera. The number of larval instars in Trichoptera has been stated as five to seven (Nielsen 1942) and six or seven (Riek 1970), so that the five determined for three species in Waikoropupu Springs falls within the recorded limits.

Seasonal changes in instar distribution

Of the five common species, four had seasonal life histories in Waikoropupu Springs and the other had a non-seasonal life history.

The life history of R. vernale (Part 4) differed from the other seasonal life histories studied in that larval growth took place from about November-December to June. Fourth instar larvae were not found after the end of April and pupation took place about the end of June. There is some doubt as to whether larval growth extends over one or two years because of the difficulty in separating early instar larvae of this species from those of Helicopsyche poutini.

The life histories of C. gunni, P. puerilis and Z. cheira extended over one year (Figs. 3.6, 3.7, 3.8) and all had similar larval size distributions on any sampling date during the study period. Second instar larvae were recorded during winter 1971 (May to August) while third and fourth instar larvae appeared in larger numbers as the season progressed. Maximum numbers of final instar larvae were present from October 1970 (when sampling began) to January-February 1971 and from August-September 1971 to January 1972.

Pupae of P. puerilis were not found at sites 1 and 4 (Fig. 3.7) and it is possible that final instar larvae migrate from these sites to shallower water prior to pupation. On 6

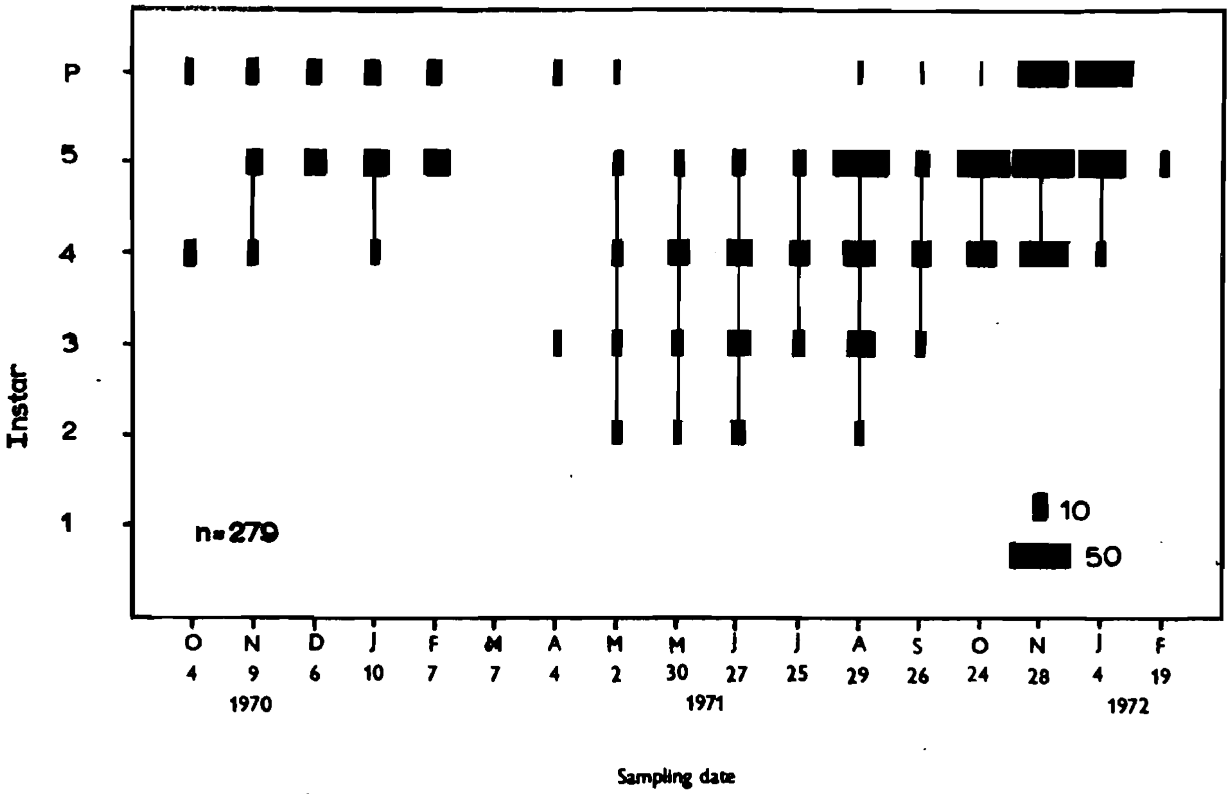


FIG. 3.6: Conuxia gunni. Instar distribution in Waikoropupu Springs from Oct 1970 to Feb 1972. Data from samples at sites 1 and 4 combined. Blank denotes that no specimens were taken in samples on that date.

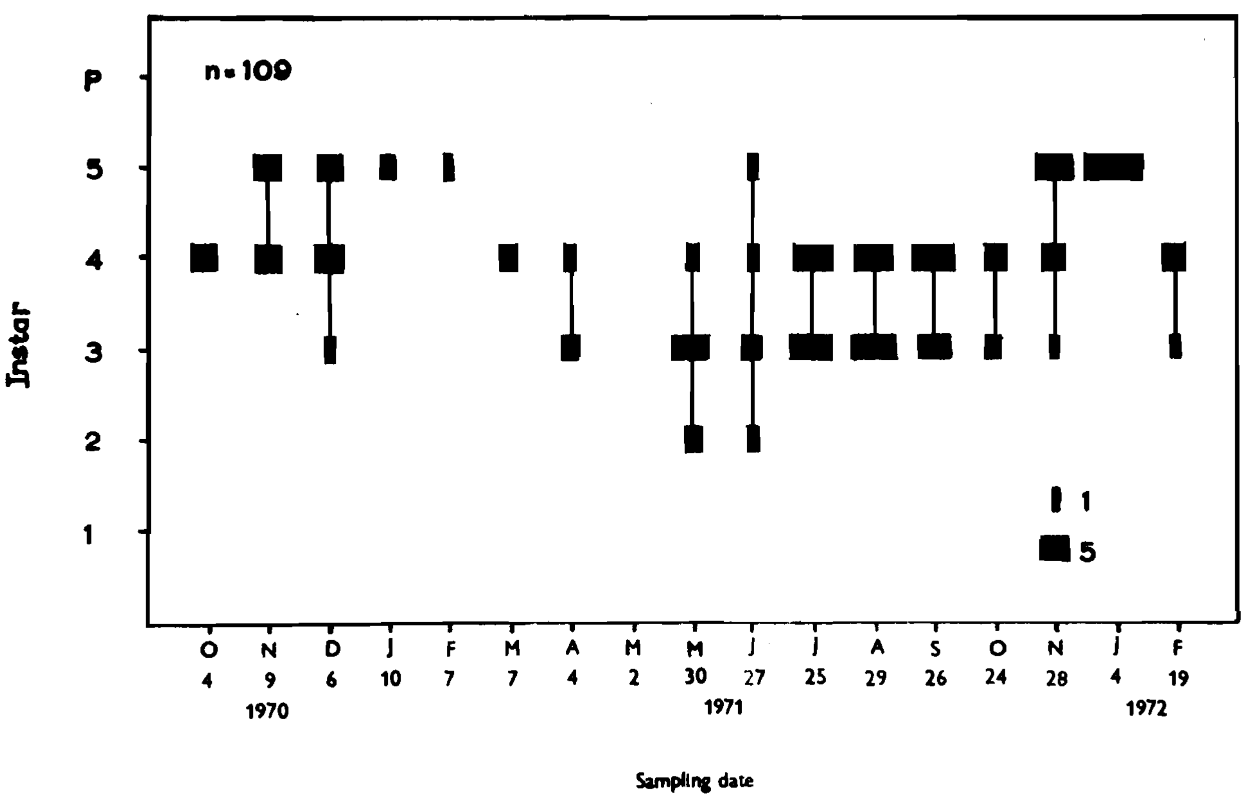


FIG. 3.7: Polyplectropus puerilis. Instar distribution in Waikoropupu Springs from Oct 1970 to Feb 1972. Data from samples at sites 1, 4 and 7 combined. Blank denotes that no specimens were taken in samples on that date.

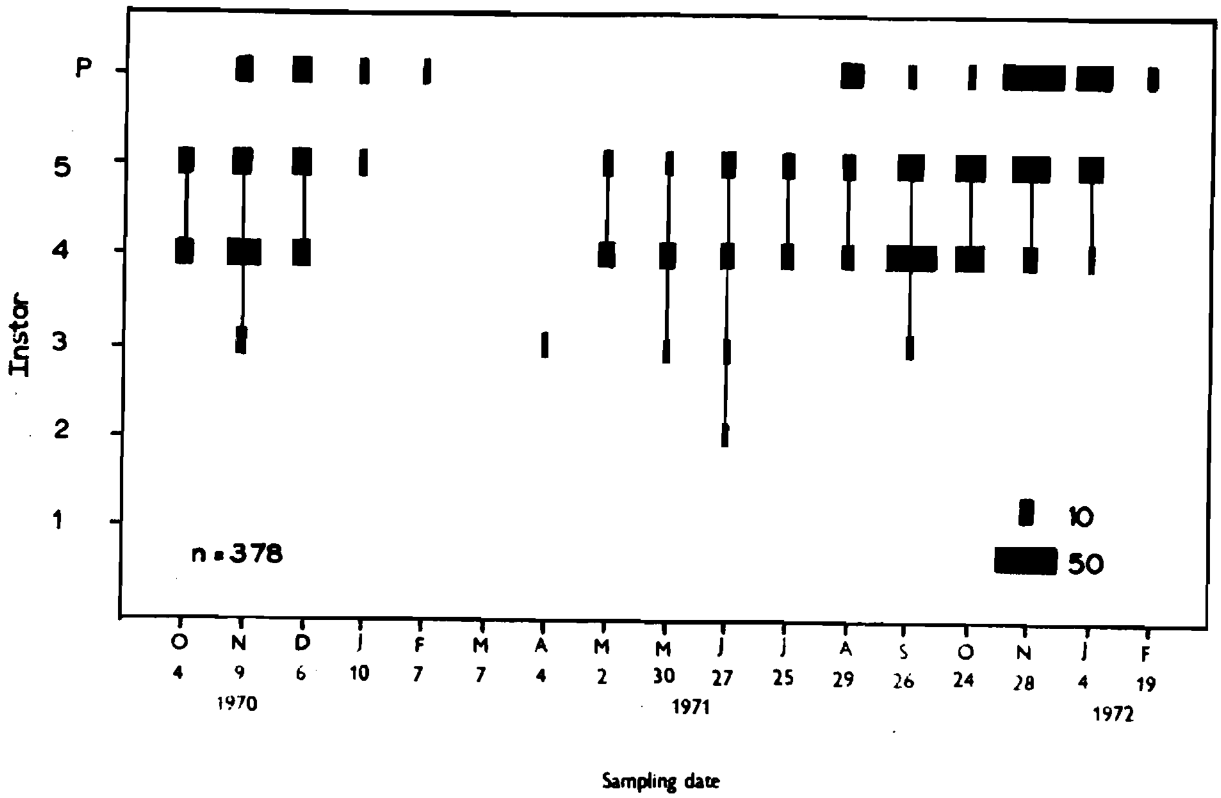


FIG. 3.8: Zelolessica cheira. Instar distribution in Waikoropupu Springs from Oct 1970 to Feb 1972. Data from samples at sites 1 and 4 combined. Blank denotes that no specimens were taken in samples on that date.

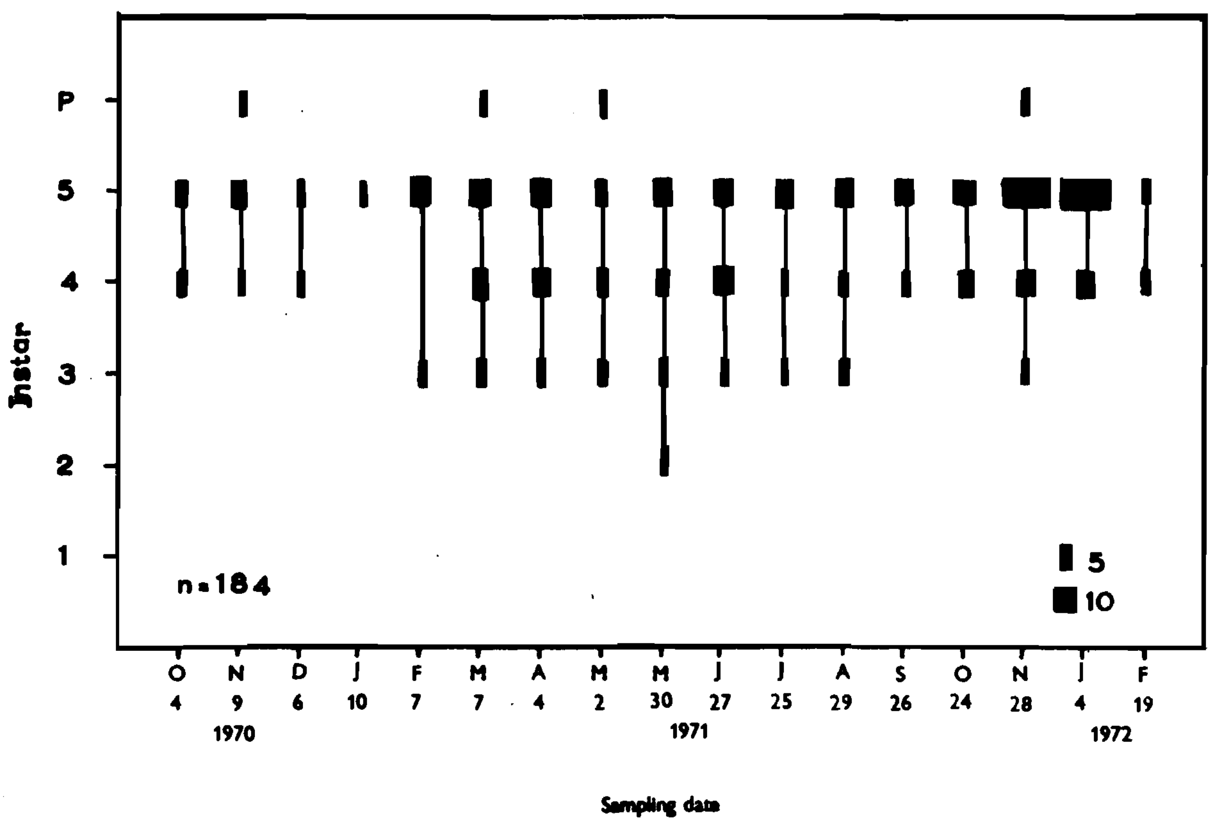


FIG. 3.9: Psilochorema tautoru. Instar distribution in Waikoropupu Springs from Oct 1970 to Feb 1972. Data from samples at all sites combined.

December 1970 final instar larvae were found in large numbers near the shoreline at peg R in water 20 cm deep. McFarlane (1937 unpublished) found that Polyplectropus sp. indet. chooses backwaters for pupation in the rivers of Canterbury.

Pupae of Z. cheira were found from November 1970 to February 1971 and from late August 1971 to February 1972. Up to fifty pupae were found in groups at site 1 in small areas of Cratoneuropsis relaxa but never in the nearby moss Fissidens rigidulus. Pupae were rarely found at site 4 (liverwort) in spite of the presence of final instar larvae there, and, when found, were not in groups nor firmly attached. This again suggests migration of final instar larvae prior to pupation.

Pupae of C. gunni were collected at both sites 1 and 4 in maximum numbers from November 1970 to February 1971 and from November 1971 to January 1972, which is similar to the pupal period of Z. cheira.

No data are available for C. gunni or Z. cheira in other localities but Hudson (1904) studied P. puerilis in an unrecorded locality. In the Springs, early and middle instar larvae are present in winter and early spring whereas Hudson stated that larvae were scarce at these times. In both the Springs and Hudson's locality, larvae were fully grown in summer. While pupation occurs during spring and summer at Waikoropupu, Hudson considered that the adults present in November in his locality had overwintered as pupae. He recorded adults as nocturnal, with a flight period from November to April. The flight period was not investigated in the present study but emergence probably began in late spring.

In contrast to the four species described above, Ps. tautoru has a non-seasonal life history (Fig. 3.9). No first and few second instar larvae were recovered in the samples at

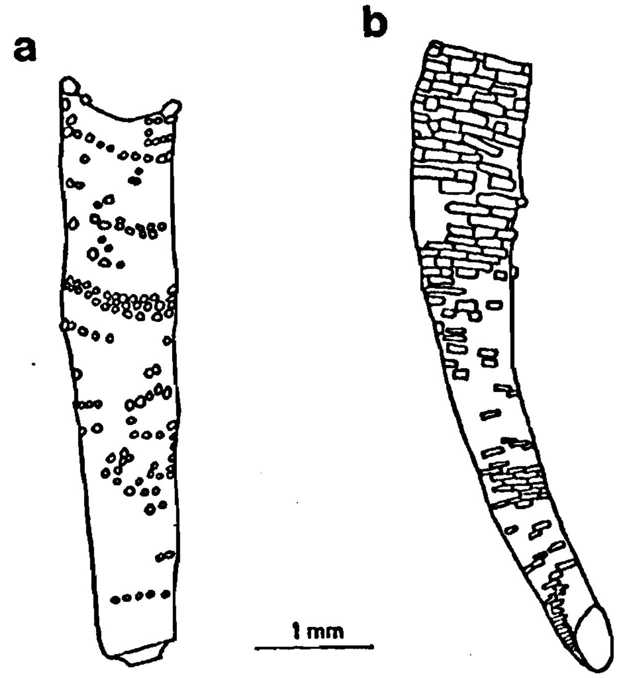


FIG. 3.10: Conuxia gunni and Zelolessica cheira. Typical cases of final instar larvae.

a. Conuxia gunni
b. Zelolessica cheira

sites 1 and 4. Third instar larvae were found from February to August and in November 1971 but final instar larvae were found in every month of the year. Pupae were recorded from moss and liverwort samples in November 1970 and March, May and November 1971. These data indicate that some individuals of most instars are present at all times of the year, suggesting that larval growth is not confined to a particular season but may extend all year round.

Larval and pupal cases and larval nets

The larvae of Rhyacophilidae are free-living and larval Polycentropodidae are the only caddis larvae present in the Springs that build nets. The pupae of both families are enclosed in cases. Sericostomatidae, Helicophidae and Helicopsychidae have both larval and pupal cases.

Larval cases of C. gunni are cylindrical and slightly curved with a characteristic projection and round vent at the posterior end (Fig. 3.10a). The length of the case increases from 0.8 mm (F-3 instar) to about 7 mm (F instar). The usual material of case construction changes during larval development from sand (F-3 instar) through silk and sand (F-2, F-1 instar) to silk with a few grains of sand attached (F instar). The pupal case, about 6 mm long, is made of smooth brown silk and is firmly attached to moss or liverwort filaments with ropes of silk.

Larval cases of Z. cheira are curved and taper gradually to a characteristic oblique vent at the posterior end (Fig. 3.10b). Larval case length increases from 2.5 mm (F-2 instar) to 8.5 mm (F instar) but the cylindrical pupal case is only 6 mm long. Case material of larvae and pupae varied with the habitat of the animal. In moss (mainly *Cratoneuropsis relaxa*) cases were built of rectangles of moss and occasional sand grains (0.2 mm diameter) incorporated in a regular pattern. In liverwort (mainly *Lophocolea* spp.) cases were built of circles of *Lophocolea* leaves (0.1-0.3 mm in diameter).

Larval cases of instars 1 - 4 of *R. vernale* are spiral (Part 4) and are indistinguishable with the naked eye from those of *Helicopsyche* spp. Cases of the final instar larva however, possess a distinctive tubular projection of coarse sand particles, making them easily recognizable. Prior to pupation the larval case is firmly attached to the underside of a large boulder and the opening is closed with a silken plate.

Larval nets of *P. puerilis* were not observed while diving in the Springs but larvae reared in a moderate water velocity in the laboratory built funnel-shaped nets about 7 cm long by 4 cm wide. The nets were kept open partly by attachment to stones and the aquarium walls, and partly by the current.

Polyplectropus puerilis pupated on the undersides of boulders in cases of fine gravel, but its silken cocoon was finer than those of the rhyacophilids *Ps. tautoru* and *H. parumbripennis*. These species pupated within a tough brown cocoon enclosed by a case of fine gravel, similar to the pupal case of *H. parumbripennis* described by Pendergrast and Cowley (1966).

Pupal development and emergence

The pupal stage of *P. puerilis* lasted for 12 days in the laboratory at a water temperature of 20°C. Hudson (1904) described the pupa of this species but was unable to rear it to the adult stage.

Emergence of *Z. cheira* in the laboratory was observed on two occasions. Pupae left their pupal cases and swam to the surface using, in one instance, the first and third pairs of legs and in the other instance, all three pairs of legs which are fringed with long hairs. As with *P. puerilis* and *R. vernale* (see Part 4), emergence took place at the surface of the water and the adult was able to fly immediately.

Adults

Most collecting was done during summer and for identification purposes only, so that no information is available on the flight periods of the Trichoptera except for *Rakiura vernale*. This species had an unusually short and early flight period from mid-September to early October (Part 4). Dates of collection of adult Trichoptera are recorded in Appendix 5.

PLECOPTERA

Megaleptoperla diminuta (Gripopterygidae)

Eggs

Eggs dissected from an adult female were white, oval and of length 0.42 mm. The eggs contained first instar larvae of headwidth 0.25 mm. This suggests that the species is ovoviviparous, as are *Capnia bifrons* (Capniidae) (Brinck 1949) and several other species of Plecoptera (Hynes 1970). Brinck recorded that females of *C. bifrons* are fertilised soon after emergence but continue to feed for about 21 days while their eggs develop before being laid and the same may be the case with *M. diminuta*.

Determination of larval instars

An attempt was made to separate larvae using head-

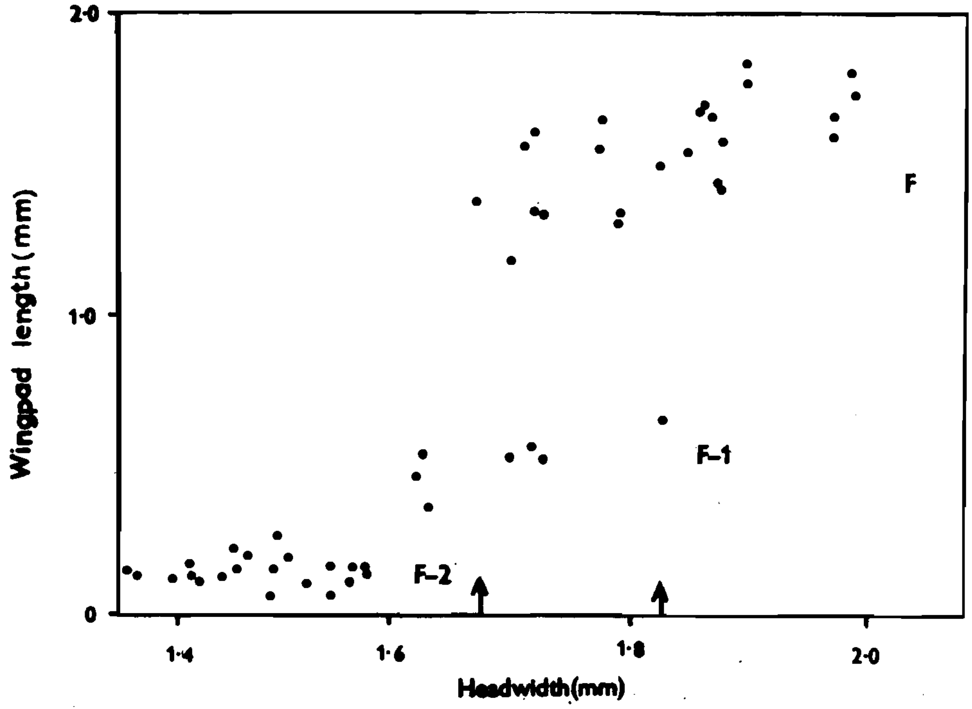


FIG. 3.11: Megaleptoperla diminuta. Relation between headwidth and length of wingpads for the later instars. Arrows indicate mean headwidths of instars.

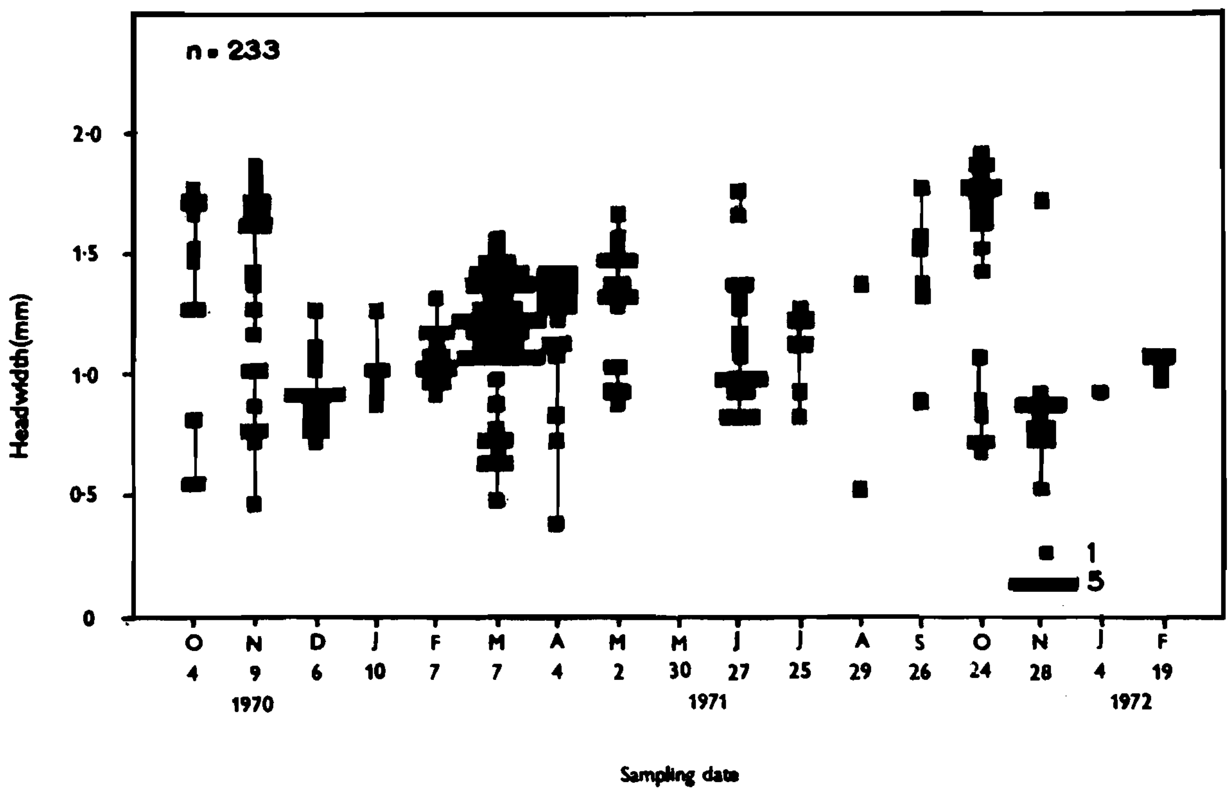


FIG. 3.12: Megaleptoperla diminuta. Size distribution in Waikoropupu Springs from Oct 1970 to Feb 1972. Data from samples at all sites combined. A blank denotes that no specimens were taken in samples on that date.

width data but the headwidth range of final (F) and penultimate (F-1) instar larvae overlapped. Fortunately, F and F-1 instar larvae could be separated by wingpad length (Fig. 3.11) but F-2 and earlier instars could not be separated by this method. The mean headwidth of F instar larvae was 1.82 mm and that of F-1 instar larvae 1.67 mm, giving a quotient at ecdysis of 1.09.

Laboratory rearing of individual specimens of middle instar larvae yielded a quotient at ecdysis (pronotum) of 1.10-1.18, corresponding to a quotient at ecdysis (headwidth) of 1.08-1.14 (Appendix 6b). The mean value of 1.10 for the quotient at ecdysis (headwidth), experimentally derived for middle instar larvae is therefore almost the same as that derived from measurements of late instar larvae from field samples. Using a factor for the quotient at ecdysis (headwidth) of 1.09, the number of instars was calculated to be 25 whereas using a factor of 1.10, the number of instars was calculated to be 22. However, until the species is reared from the egg to the final instar larva in the laboratory, the number of instars cannot be determined with any certainty.

Seasonal changes in size distribution

The earliest instar larvae were not recovered in the field but larvae of headwidths 0.43-0.54 mm (possible instars 6 to 9) were found in October and November 1970 and March, April, August and November 1971 (Fig. 3.12). Final instar larvae were taken in samples in October and November 1970 and in June, October and November 1971 (Fig. 3.12) but numbers were small. It is possible that stonefly larvae of later instars migrate towards the shore prior to emergence, as was observed by Lillehammer (1966) in a Norwegian river. Final instar exuviae were found from August to November 1971, but it is not known whether they were present prior to August 1971. Adults were netted on one occasion only, at the edge of the Springs just before noon on a warm calm day (1 May 1971).

Data on larval size distribution for this species are difficult to interpret. The main emergence period may be in spring (September-November inclusive) with emergence of some advanced specimens in autumn (March-May inclusive) or emergence may continue over an extended period from late autumn to spring.

ODONATA AND EPHEMEROPTERA

The dates on which adult *Xanthocnemis zealandica*, *Deleatidium myzobranchia* and *Zephlebia scita* were collected or observed flying at Waikoropupu Springs are recorded in Appendix 5.

Adults of *X. zealandica* were flying from 4 December 1970 to 6 February 1971 and from 1 January to 19 February 1972. Hudson (1904) also observed that the species appears in largest numbers in December but becomes rarer towards the end of summer and noted that it only flies on bright sunny days.

Imagos of *D. myzobranchia* were taken from November 1970 to February 1971 and from May to August 1971 but no comparative data are available.

Swarms of imagos of *Z. scita* were observed in February, May and October 1971 and January and February 1972. Norrie (1969 unpublished) also recorded emergence of this species in late spring, summer and autumn from an Auckland stream. Imagos at Waikoropupu Springs swarmed 4 m above the calm water of the Dancing Sands and McLean (1967) observed them

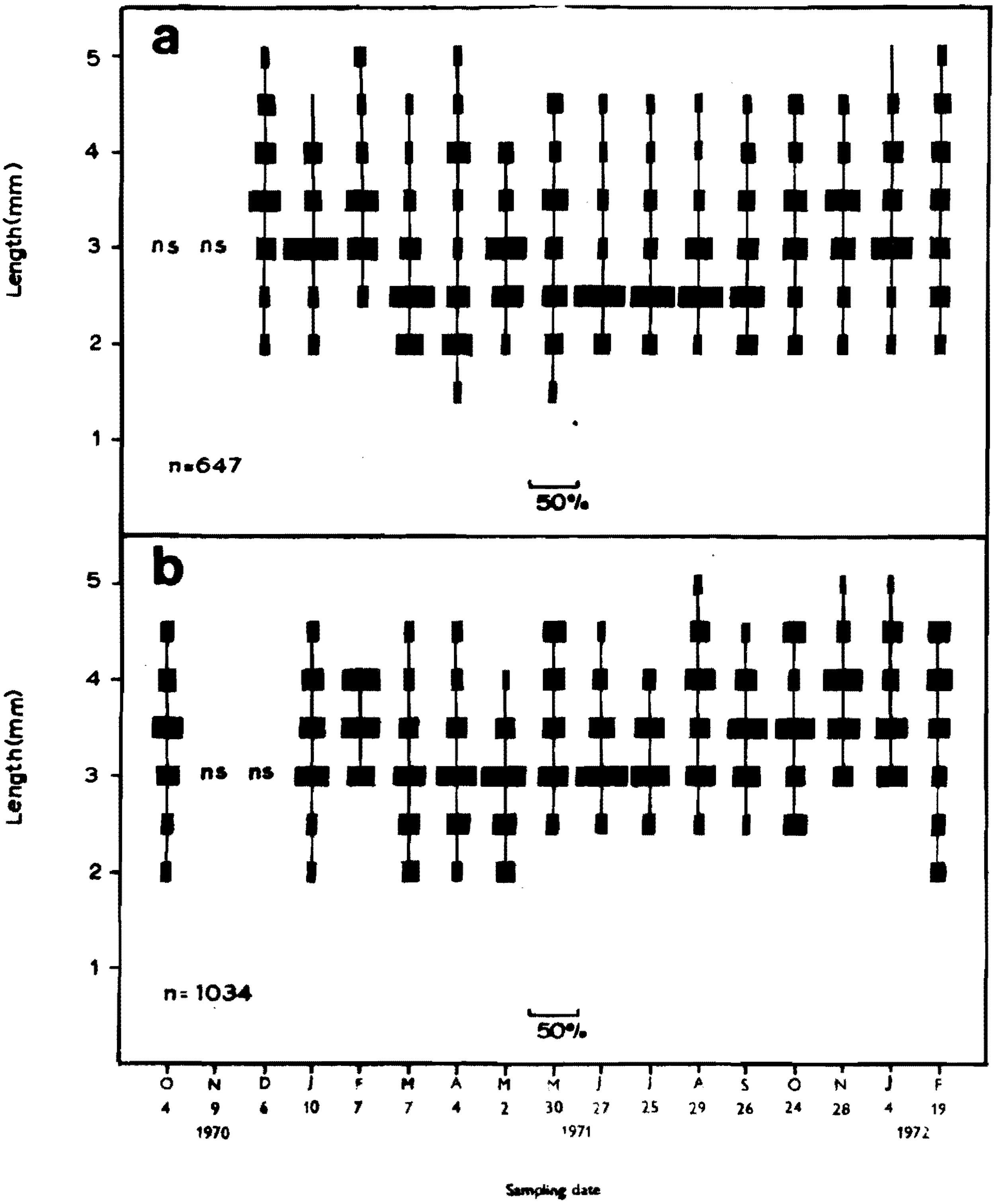


FIG. 3.13: Paracalliope karitane. Size distribution at two sites in Waikoropupu Springs from Oct 1970 to Feb 1972. "ns" denotes that no sample was taken on that date.

a. Site 1 (moss)

b. Site 4 (liverwort)

swarming at a height of 5-10 m above pools in a stream near Auckland. Isolated larvae were taken in the Springs study area but the species must have been breeding in greater numbers elsewhere.

CRUSTACEA

Paracalliope karitane (Amphipoda:Eusiridae)

Some individuals of *P. karitane* were gravid throughout the year. The pink clutch of eggs on the ventral surface of the abdomen was clearly visible to the underwater observer but very few gravid females were taken in each four-weekly sample. Eggs were oval and 0.4 mm long.

Size distribution over the study period was similar at sites 1 and 4 (Fig. 3.13a,b). Although young animals, newly released from females, measured only 0.9 mm long, animals less than 1.7 mm long were not recorded from field collections and may have been lost during the sorting process. Greatest numbers of small amphipods were present from early March to the end of May 1971 although some small specimens were present at all times of the year.

Paratya curvirostris (Decapoda:Atyidae)

Data obtained from all sites in Waikoropupu Springs over the period October 1970 to February 1972 are summarised in Fig. 3.14. During the study, only one gravid female was taken (carapace length 7.8 mm, 26 Jan 1970). All shrimps taken were of carapace length (C.L.) 4.7-9.4 mm (total length 1.9-3.8 cm) and few shrimps had a C.L. greater than 7 mm. This suggests that young shrimps of C.L. less than 4.5 mm and most mature shrimps of C.L. greater than 7.5 mm may be downstream from the study area at Waikoropupu Springs. Seasonal variation

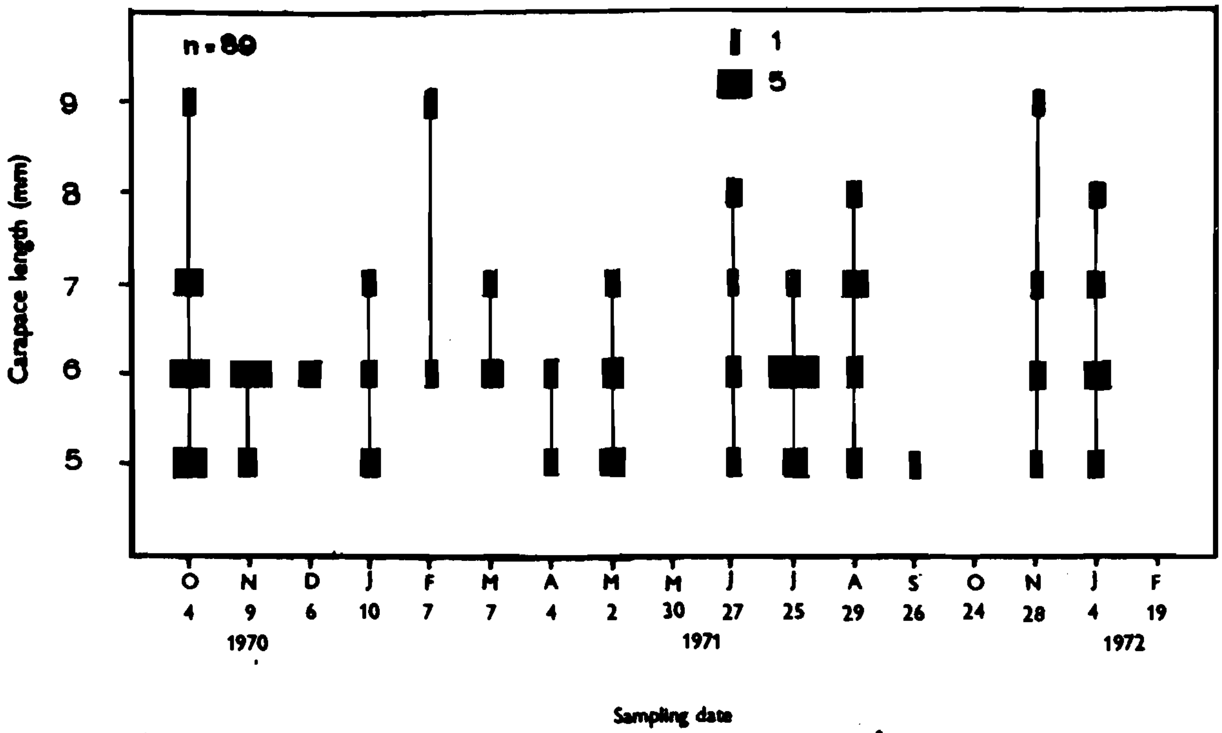


FIG. 3.14: Paratya curvirostris. Size distribution in Waikoropupu Springs from Oct 1970 to Feb 1972. Data from samples at all sites combined. A blank denotes that no specimens were taken in samples on that date.

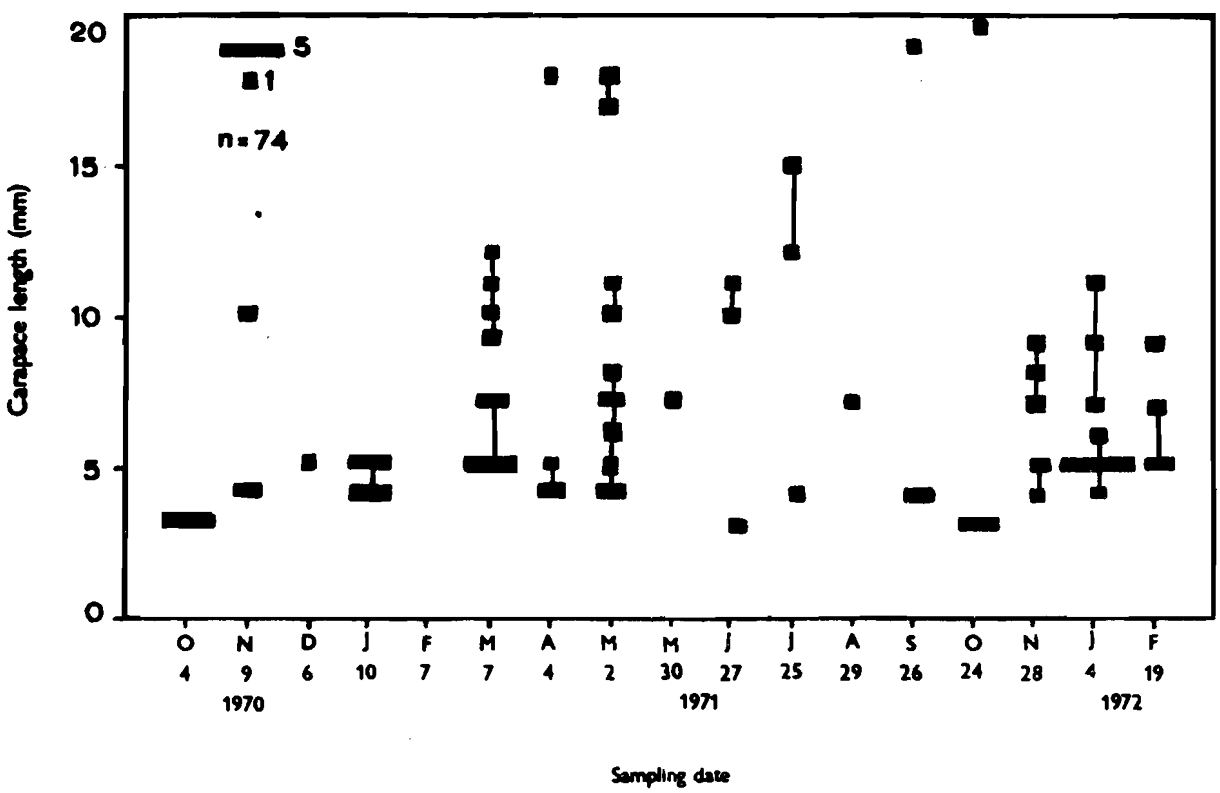


FIG. 3.15: Paranephrops planifrons. Size distribution in Waikoropupu Springs from Oct 1970 to Feb 1972. Data from samples at all sites combined. A blank denotes that no specimens were taken in samples on that date.

in the size structure of the population was not evident (Fig. 3.14).

Richardson and Yaldwyn (1958) recorded that this species bears eggs from September to April but gave no details of where they found the material examined. Extensive sampling round the edges of Waikoropupu Springs failed to find more than one gravid shrimp. Nielson (1972), working mainly in the Avon River, Canterbury, stated that gravid females keep to the shady parts of the river but results from Waikoropupu Springs suggest that they may migrate or drift downstream. Nielson also reported that "newly hatched larvae may be washed down to the mouth of the rivers quite early and undergo their subsequent development through the larval stage in the sea", return to fresh-water at a length of about 5.5 mm, and then actively migrate upstream. He recorded shrimps 5.5 mm long up to four miles (6 km) upstream from the sea, but shrimps of this length were never found in Waikoropupu Springs (6 km from the sea). The strong current in the Waikoropupu River and Springs outflow may make upstream migration of young shrimps very slow.

Paranephrops planifrons (Decapoda:Parastacidae)

The size frequency distribution of 74 specimens collected in Waikoropupu Springs between October 1970 and February 1972 is given in Fig. 3.15. Crayfish of carapace length (C.L.) 3.2-20.5 mm were taken over the course of the study, the smallest gravid female having a C.L. of 17.1 mm. Gravid females were observed, while diving, from the first week in April to the end of June 1971. Young crayfish were collected in October 1970 and in late June to late October 1971.

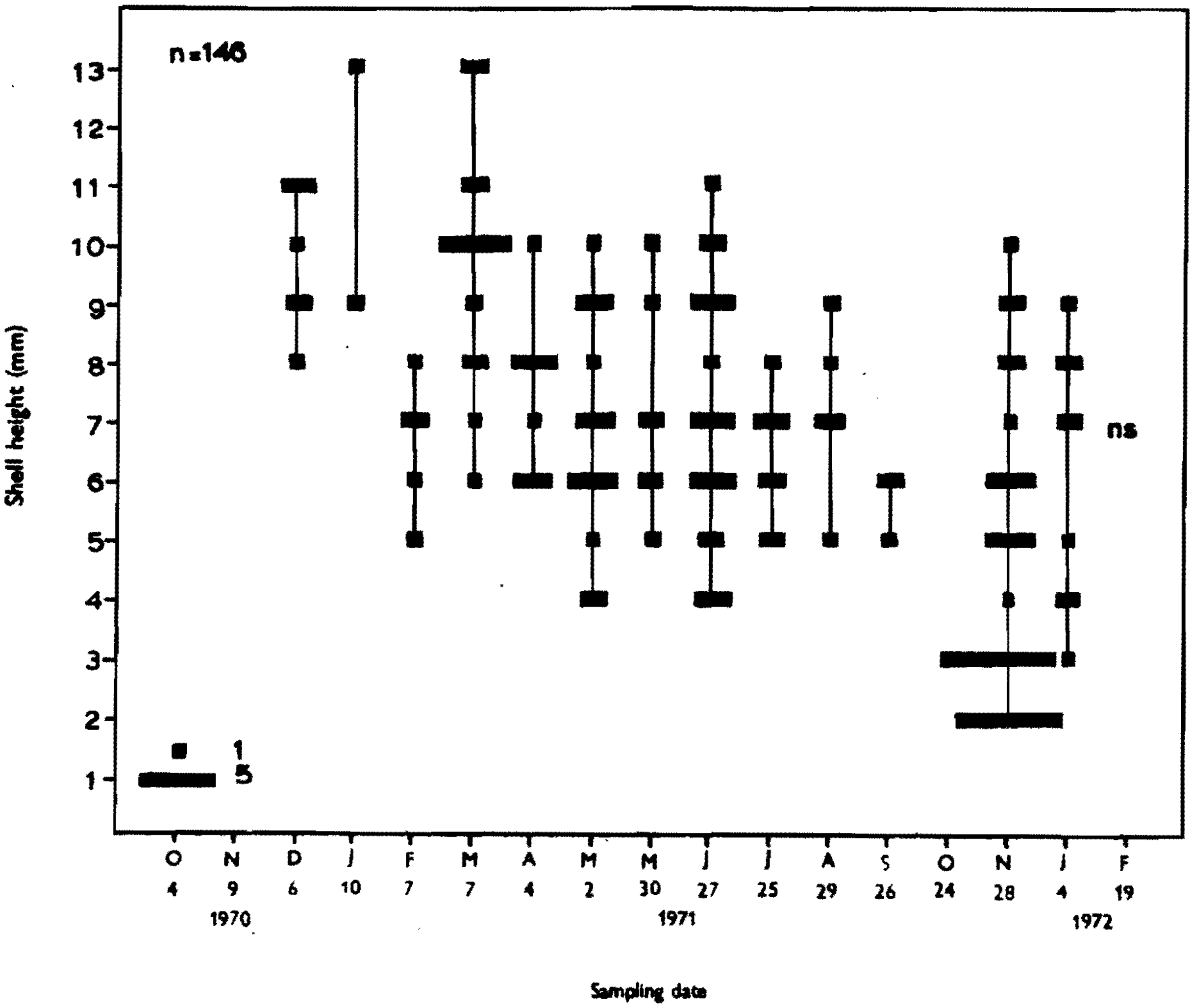


FIG. 3.16: Lymnaea columella. Size distribution in Waikoropupu Springs from Oct 1970 to Feb 1972. Data from samples at site 7 only. "ns" denotes that no sample was taken on that date and a blank denotes that no specimens were taken in samples on that date.

Hopkins (1967b) studied *P. planifrons* in the Mangatere River, Wairarapa and found a carapace length at hatching of 3.5 mm and at maturity of 17.0 mm, which is comparable to that in Waikoropupu Springs. The breeding period extended from April to December (Hopkins 1967a), much longer than that apparently occurring in Waikoropupu Springs. Individuals in the population studied by Hopkins (1967b) lived for about three years but the generation time in Waikoropupu Springs has not been determined.

GASTROPODA

Lymnaea columella (Lymnaeidae)

Information was obtained from four-weekly sampling of watercress from October 1970 to January 1972. Because of the small number of specimens taken in samples, the period of reproductive activity for this species in Waikoropupu Springs could not be determined.

Egg masses obtained from Waikoropupu Springs on 16 April 1972 contained 4-20 eggs. Eggs laid in the laboratory at 12^{o}C hatched in about 30 days into snails of shell height 0.2 mm. Shells of most specimens taken were 4-13 mm high (Fig. 3.16) and no shells less than 4 mm high were found between December 1970 and September 1971 (inclusive). However, the samples taken in November 1971 contained specimens in the 2 and 3 mm size classes and may have been taken unintentionally from a different microhabitat within the sampling area. The predominance of large specimens in the watercress samples suggests that watercress within the sampling area (site 7) is only part of the habitat of this species. Early stages of *L. columella* may be on the substrate beneath the free-floating watercress or they may be inshore of the sampling area.

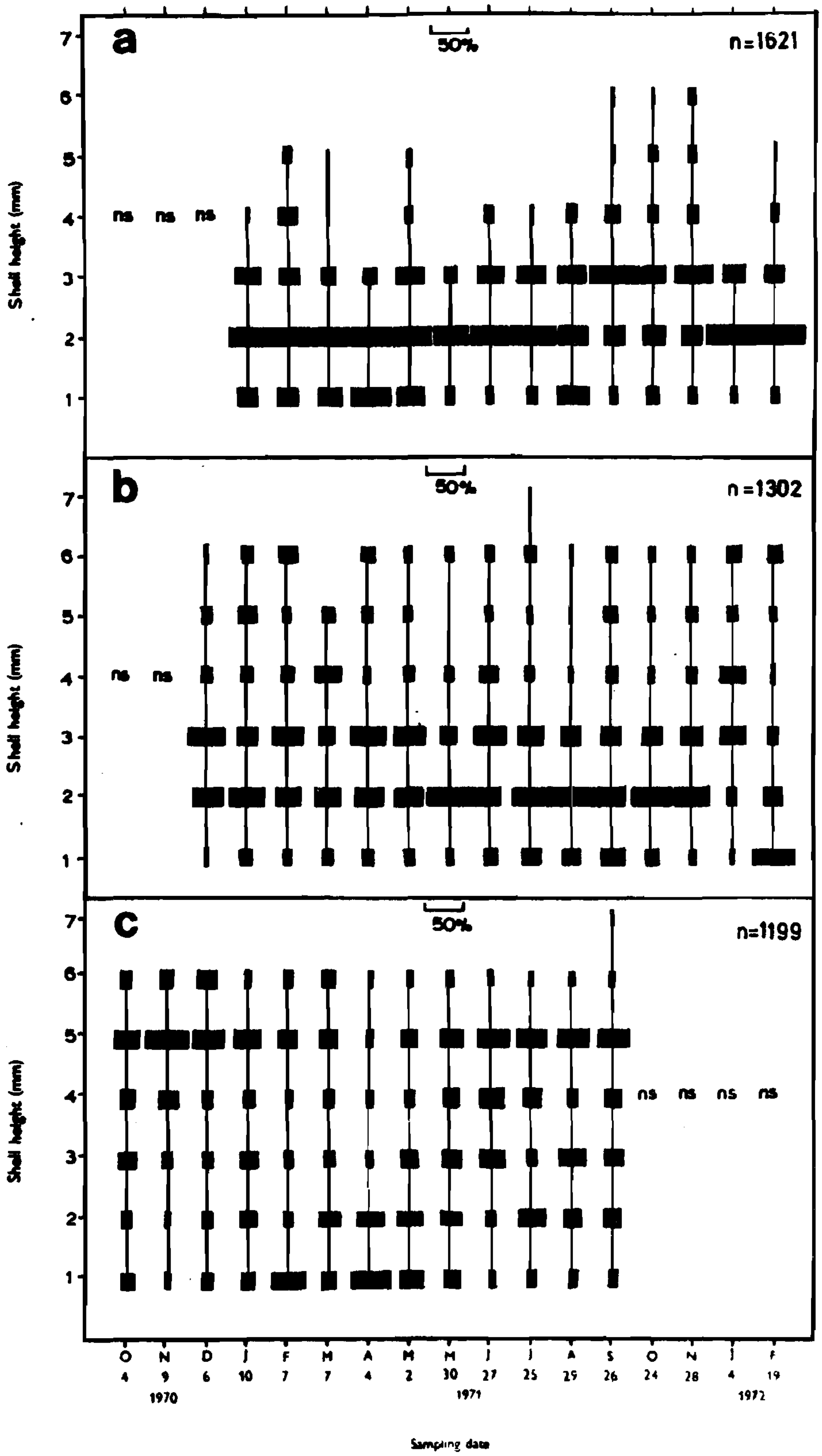


FIG. 3.17: <u>Potamopyrgus antipodarum</u>. Size distribution at three sites in Waikoropupu Springs from Oct 1970 to Feb 1972. "ns" denotes that no sample was taken on that date.

a. Site 4 (liverwort)

b. Site 1 (moss)

c. Site 7 (watercress)

Potamopyrgus antipodarum (Hydrobiidae)

In Waikoropupu Springs, the population of *P. antipodarum* possessed a different size structure at the three regular sampling sites (Fig. 3.17 a,b,c). At site 4 (liverwort), snails in the 1-3 mm size classes predominated with few snails in the 4-6 mm size classes; at site 1 (moss), 2 and 3 mm size classes were the most common but some larger specimens were also present whereas at site 7 (watercress), all size classes from 1-7 mm were well represented in most months of the year.

Winterbourn (1970b), in a study of *P. antipodarum* in Tiritea Stream near Palmerston North, N.Z., found large numbers of young snails in sediments and willow roots and attributed their abundance to the shelter available. In the Springs more small snails were found at site 4 (liverwort) than at site 7 (watercress). Compared with site 7, site 4 has much higher water velocities and presumably less shelter available, so that Winterbourn's shelter explanation is not applicable. At site 4, a very small percentage of snails had a shell height greater than 4.5 mm, at which height snails in the laboratory released embryos. It is likely that this species is not reproducing to any extent at site 4 and small snails found there may have migrated into the area.

This species seems to reproduce all year round at sóme sites as small snails were present throughout the year. A similar situation has been reported for *P. antipodarum* in a stream and two ponds, although in the stream, where the water temperature varied from 8-19^{o}C, a higher proportion of adult snails contained embryos in late spring and early summer than during the rest of the year (Winterbourn 1970b).

At site 7 the greatest percentage of small snails was present from February to May 1971 (Fig. 3.17c). This histogram suggests that the size class of 1-2 mm in early February to early May 1971 grew so that by June to September 1971 the larger size classes were well represented. Thus, these snails probably took less than one year to reach maturity in the Springs. Winterbourn (1970b) reported from laboratory studies that at a mean water temperature of 18°C, maturity may be attained in six months and the release of embryos can occur in nine months. This is a slightly faster growth rate than that inferred from the present field study at 12°C.

VERTEBRATA

Anguilla australis schmidtii and *Anguilla dieffenbachii* (Pisces:Anguillidae)

Both short- and long-finned eels were present in the Springs. Specimens of *Anguilla australis schmidtii* were were only 11.7-20 cm in length, and should therefore belong to the 5, 6 or 7 year age classes of Cairns (1941). They were found in beds of floating watercress from September to October 1970 and October 1971 to January 1972.

Anguilla dieffenbachii about 0.90 m long were observed in the Main Spring between November 1970 and March 1971 and again in late June 1971.

Birds

Dates on which birds were seen feeding or were sighted at Waikoropupu Springs are recorded in Appendix 7. Different species were seen feeding in different parts of the Springs: pukekos and wekas in the watercress beds around the edges of the Main Spring and Dancing Sands; fantails above the study area; little shags and grey ducks sometimes in the study area near the island but usually in the Springs outflow, and white faced herons only in the Springs outflow.

COMMENTS ON THEIR LIFE HISTORIES

In Waikoropupu Springs, most species of insects investigated apparently had seasonal life histories, as has been found in other cold springs of constant temperature e.g. general observations on a spring in L. Wigry, Poland (Demel 1923); Trichoptera (14 spp.) (Nielsen 1942) and an Ephemeropteran, Plecoptera (3 spp.) and Diptera (2 spp.) (Thorup 1963) in springs in Denmark and Trichoptera (2 spp.) in spring-fed water-cress beds in the United Kingdom (Gower 1965, 1967). However, the life history of Psilochorema tautoru (Trichoptera: Rhyacophilidae) was apparently non-seasonal, as was the life history of Wormaldia occipitalis (Trichoptera:Philopotamidae) in Danish springs (Nielsen 1942). The life histories of two species of Plecoptera common in springs in Sweden are non-seasonal, with larval populations composed of many age classes and having extended emergence periods (Briuck 1949).

Except for the crayfish Paranephrops planifrons, the five species of crustaceans and molluscs studied in Waikoropupu Springs appeared to have non-seasonal life histories, as has been shown elsewhere for these groups. Pomacea paludosa (Gastropoda) in Silver Springs, Florida had a non-seasonal life history with increased reproduction in the summer (Odum 1957a); Asellus aquaticus (Isopoda) and Ancylus fluviatilis (Ancylidae) in cold springs in Denmark both showed non-seasonal life histories (Thorup 1963).

Seasonal life histories of aquatic animals in cold springs may be adapted to take advantage of seasonal changes in the availability of food (Odum 1957a). In cold springs, the insects, which spend part of their life history out of the water, generally have seasonal life histories while crustaceans and molluscs, which do not leave the water, generally have non-seasonal life histories. This suggests that the life histories of aquatic insects in cold springs may be adapted to take advantage also of favourable air temperatures during the flight period, as are the life histories of insects in Lapland streams (Ulfstrand 1968).

PART 4

THE DISTRIBUTION AND LIFE HISTORY OF RAKIURA VERNALE (TRICHOPTERA:HELICOPSYCHIDAE)

Journal of the Royal Society of New Zealand, 1973, Vol. 3, No. 2, pp. 295-304, 16 figs

The Distribution and Life History of *Rakiura vernale* (Trichoptera: Helicopsychidae)

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[*Received by the Editor, 27 July 1972*]

Abstract

The distribution of *Rakiura vernale* (Trichoptera: Helicopsychidae) in New Zealand suggests that it may be a glacial relict. It is known from several localities in the Stewart Island region and has also been found in the cold Waikoropupu Springs, Takaka (11.7°C all year round).

The morphology of the larva and its spiral case are described. The life history of the species in Waikoropupu Springs is reported and discussed. Emergence of adults takes place unusually early in spring; the flight period lasts less than four weeks. Egg laying and hatching follow closely but it is uncertain whether larval growth extends over one or two years. The final instar is present in autumn and the pupal stage lasts through winter.

INTRODUCTION

To date, *Rakiura vernale* McFarlane, 1973, has been collected from only two localities in New Zealand, Waikoropupu Springs in the Nelson district and Stewart Island together with its outlying islands. The species has not yet been found between these places. The restricted distribution of this species prompted investigation and suggested that it could be a glacial relict which has been able to survive in cold springs at an otherwise unsuitable latitude (Bornhauser, 1913).

Apart from a study by Glasgow (1936) of the life histories of *Hydropsyche colonica* and *Diplectrona zealandensis* (referred to as *H. philpotti* by Glasgow; see McFarlane (1973)) and unpublished theses by McFarlane (1937), Allan (1958), Rowley-Smith (1962), Babington (1967), and Norrie (1969) there are no reported studies on the life histories of any New Zealand caddisflies.

MATERIALS AND METHODS

Larvae and pupae of *Rakiura vernale* were collected by hand from the undersides of boulders in Waikoropupu Springs every four weeks and were immediately preserved in 70 percent ethanol. Because of the small size of the population, fewer than ten individuals were collected on each occasion. Adults were taken by sweep netting each week during the emergence period. Head capsule widths were measured in an attempt to determine larval instars. Measurements were made across the widest part of the head using a Leitz micrometer eyepiece attached to a binocular microscope (total magnification ×25). The number of larvae of each headwidth was plotted to find the number of instars for the species. Water velocities were measured 10 cm above the substrate using a Gurley current meter Model No. 622-F.

Laboratory Experiments

Eggs were placed in non-aerated Springs water in solid watch glasses (4 cm × 4 cm × 1.5 cm) covered with polythene to prevent evaporation. Food, in the form of plant detritus, was added when the eggs had hatched.

Larvae and pupae were maintained in covered plastic petri dishes (9 cm diameter) containing Springs water, stones, diatoms and other algae. Five animals were placed in each dish at 12°C and the dishes were transferred to one of four constant temperatures: 6°C, 12°C, 16°C and 20°C. Two refrigerators maintained at 12°C ± 1C° were fitted with lighting in the form of two fluorescent tubes each of 14 watts, giving a light intensity in the centre of the refrigerator of 1700 lux. Refrigerators were maintained on a "winter" daylength of 8 hours light followed by 16 hours dark (hereafter referred to as L/D: 8/16) or a "summer" daylength of 16 hours light followed by 8 hours dark (L/D: 16/8). Adults were maintained in an oviposition aquarium of the type described by Bjarnov and Thorup (1970).

DESCRIPTION OF LARVA (Final instar)
Rakiura vernale McFarlane, 1973 (Figs 1–8)

Measurements. Length 6.5 mm; head length 0.91 mm from front of clypeus to posterior edge of carina, width 0.84 mm; pronotum length 0.45 mm, width 1.25 mm.

General Description. Stout, pale green, cylindrical, eruciform larva, curved to fit spiral case. The carinate head, when retracted, acts as an "operculum". Head, pronotum and legs heavily sclerotised. Pronotum, mesonotum and pygopods lightly sclerotised. No sclerotisation on sterna of thoracic segments.

Head (Fig. 1). Dorsal surface uniformly mid-brown; clypeus distinct; head completely carinate posterior to eye spots (Fig. 8). Both mandibles bearing brushes of setae on the inner sides. Antennae in a groove and inconspicuous, less than three times as long as wide. Genae not meeting ventrally, no gular sclerite; gular area membranous.

Thorax: *Pronotum* (Fig. 2). Broad and uniformly mid-brown with a row of evenly-spaced hairs around a carina towards the posterior edge. Surface of pronotum reflected downwards laterally and posteriorly to carina (Fig. 8). Anterior edge on each side projects forwards and bears ten spines. *Mesonotum* (Fig. 3). Lightly sclerotised with tufts of hairs at anterior corners; only anterior edge pigmented. *Metanotum* (Fig. 4). Not sclerotised. *Legs* (Figs 5, 6, 7). Pale brown with dark brown areas at some joints; forelegs relatively short and thick by comparison with elongate middle and hind legs. Tarsal claws one-third as long as tarsus.

Abdomen of nine clearly visible segments with a tenth at base of pygopods. First and eighth segments each have two lateral oblique humps bearing a row of short yellow hairs. *Pygopods* small, lightly pigmented and surrounded by a few hairs. Main claw chisel-shaped and blunt, accessory dorsal claw short and sharp. Dorsal spur very small.

Remarks: Third and fourth instar larvae of *R. vernale* build spiral cases that, to the unaided eye, are indistinguishable from those of *Helicopsyche*. However, larvae of *R. vernale* can be distinguished from larvae of species of *Helicopsyche* by the presence of the carinate head and by the angle of the head relative to the pronotum (Fig. 8).

McFarlane (1973) remarked on the doubtful taxonomic position of this genus with the Helicopsychidae, but suggested that it was less ill-placed here than elsewhere. Keys to the larvae of Trichoptera would not always place the final instar larva of *R. vernale* in the family Helicopsychidae. Both Ross (1944) and Riek (1970) used the anal hook as a definitive feature of larval Helicopsychidae, describing the second tooth of the anal hook as comb-like. However, the second tooth of the anal hook of *R. vernale* is short and sharp.

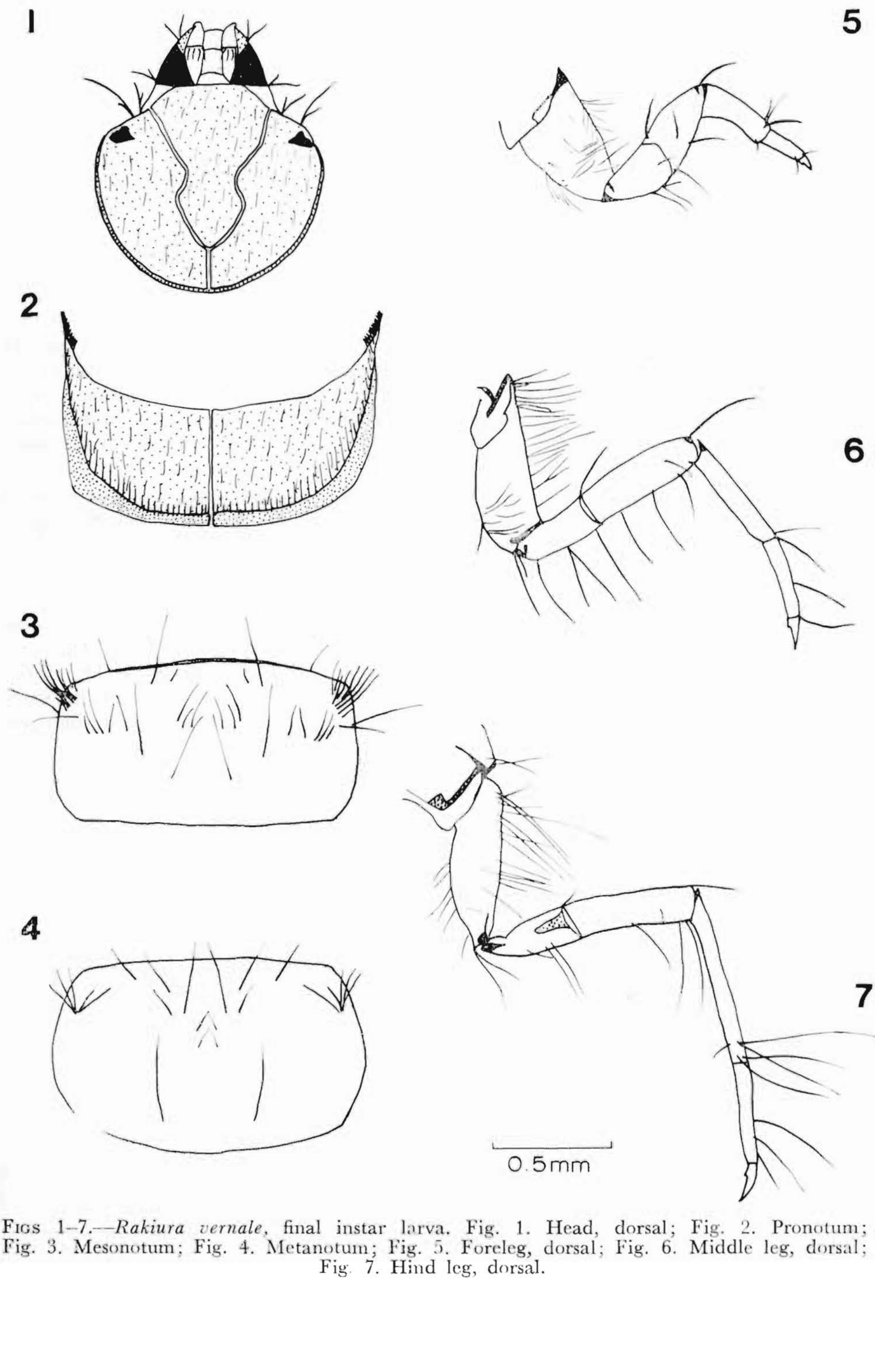
Material Examined

Waikoropupu Springs, Takaka: 8 pre-pupae, 4 final instar larvae, 28.vi.71; 8 late pupae, 29.viii.71; 1 first instar larva, 12 second instar larvae, 8 third and fourth instar larvae, 9.x.71, F. B. Michaelis; Fish Creek, Takaka, 3 larvae, 29.v.71, F. B. Michaelis.

Murderer's Bay, Big South Cape Island, 1 larva, 4 pupae, 28.viii.64, P. M. Johns; Sealer's Bay, Codfish Island, 2 larvae, 8.xii.66, J. I. Townsend; Stream at Traill's Camp, N. Arm, Paterson Inlet, Stewart Island, 2 larvae, 10.xii.68, A. G. McFarlane; Mill Creek, Paterson Inlet, Stewart Island, 10.xii.68, A. G. McFarlane; Euchre Creek, Paterson Inlet, Stewart Island, 1 larva, 1 empty pupal case, 13.xii.68, A. G. McFarlane.

Additional larval material examined by A. G. McFarlane has been collected by L. J. Dumbleton from Tributary streams of Rakeahua R., Stewart Island, in January 1967 and Stony Creek, Stewart Island, 11.ii.68.

All material examined is held in the collection of the Canterbury Museum, Christchurch.



FIGS 1–7.—*Rakiura vernale*, final instar larva. Fig. 1. Head, dorsal; Fig. 2. Pronotum; Fig. 3. Mesonotum; Fig. 4. Metanotum; Fig. 5. Foreleg, dorsal; Fig. 6. Middle leg, dorsal; Fig. 7. Hind leg, dorsal.

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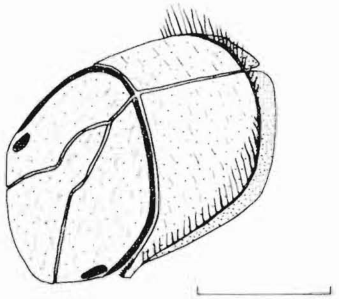


FIG. 8.—*Rakiura vernale*, final instar larva showing carinae around head and pronotum and angle of head relative to pronotum. Scale bar represents 0.5 mm.

DISTRIBUTION

Larvae of *R. vernale* are known only from Stewart Island and its outlying islands (Codfish Island and Big South Cape Island) and from Takaka (Fig. 9). At Takaka, the species has been found only in Waikoropupu Springs and, in smaller numbers, in the spring-fed Fish Creek, 400 m from the Springs. It is possible, but unlikely, that this species has been overlooked in other localities or mistaken for a species of *Helicopsyche* (Trichoptera: Helicopsychidae) as they both have similar larval cases. Specimens of the genus *Helicopsyche* have been collected from many areas in the South Island.

One possible reason for the distribution of *R. vernale* is that it can exist at latitudes as far north as Takaka because the water in Waikoropupu Springs is cool, even in summer. The water temperature at the Springs is constant at 11.7°C, and that of Fish Creek never rises above 12.5°C.

A series of experiments was carried out to investigate the possibility that *R. vernale* is a cold stenotherm. Between 10 and 50 eggs, final instar larvae and pupae were reared at each of 6°C, 12°C, 16°C and 20°C. Individuals reared at 12°C and 20°C were maintained under "winter" light conditions (L/D: 8/16) whereas individuals reared at 6°C and 16°C were kept in constant darkness because refrigerators at these temperatures were not fitted with built-in lighting.

TABLE 1. Effect of water temperature on different stages of development of Rakiura vernale in the laboratory (see text). N.D. denotes "Not Determined".

	Percentage completing stage of development. (Number of animals in each experimental group in brackets).			
Water temperature	6°C	12°C	16°C	20°C
Light conditions (L/D)	0/24	8/16	0/24	8/16
Hatching of eggs	N.D.	90 (60)	N.D.	90 (30)
Survival of final instar larvae (40 days)	100 (10)	90 (25)	100 (10)	100 (10)
Pupation of final instar larvae initiated	60 (10)	87 (30)	N.D.	N.D.
"Swimming pupae" leave pupal cases	40 (10)	95 (40)	20 (10)	30 (10)
Emergence of adults from "swimming pupae"	0 (4)	65 (38)	0 (2)	0 (3)

Results of this experiment are recorded in Table 1. Eggs hatched at both 12°C and 20°C but were not tested at 6°C and 16°C. Larvae survived at temperatures ranging from 6°C to 20°C for at least 40 days and pupated at both temperatures tested, 6°C and 12°C. A greater percentage of pupae completed development (i.e., left their pupal cases) at 12°C than at other temperatures. Adults emerged from "swimming pupae" only at 12°C but the absence of light may have precluded emergence at 6°C and 16°C. Adults did not emerge from "swimming pupae" at 20°C in spite of eight hours' light a day. This suggests that *R. vernale* may be limited to water that is less than 20°C at the time of emergence.

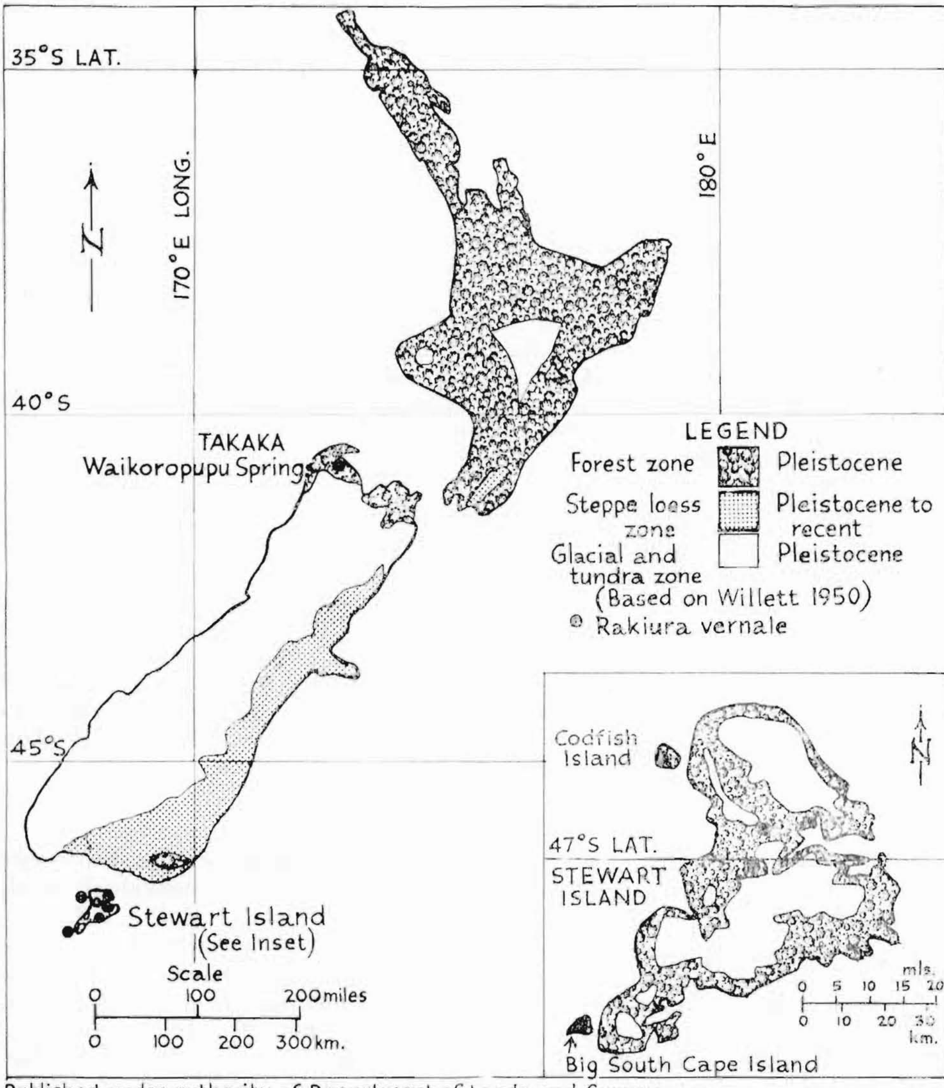


FIG. 9.—Map of New Zealand to show present distribution of *Rakiura vernale* and Pleistocene glacial and tundra zone, steppe loess zone and forest zone. Inset is an enlargement of the Stewart Island region.

WAIKOROPUPU SPRINGS—the type locality

Waikoropupu Springs, the largest cold springs in New Zealand, flow from an artesian basin in Arthur Marble, with an average water discharge of approximately 11 m^3/sec (400 cusecs). They are characterised by a constant water temperature and relatively constant velocity and chemical composition. Water from the Main

Spring of Waikoropupu Springs is hard (calcium 63 g/m³): low in dissolved oxygen (60 percent saturation): with a high specific conductivity (672 μmho/cm at 25°C). It is therefore quite unlike surface water in the Nelson-Takaka area (Taylor, unpublished data).

Remnant stands of vegetation suggest that Waikoropupu Springs were originally surrounded by podocarp-hardwood forest (*Dacrydium cupressinum, Podocarpus totara, Nothofagus* spp.). This cover was removed prior to about 1904. Today the Springs are largely surrounded by scrub including indigenous manuka and kanuka (*Leptospermum scoparium* and *L. ericoides*) and the adventives gorse (*Ulex europaeus*) and broom (*Cytisus scoparius*). Some of the shoreline of the springs has been converted to grass for access and recreation.

Larvae and pupae of *R. vernale* were found where water velocities ranged from 25 cm/sec to 140 cm/sec, i.e., medium to very strong (Berg, 1948), and where the water depth was less than 1 m and generally about 40 cm. The substrate in this area consisted mainly of boulders (average diameter about 20 cm), some gravel and coarse sand. The upper surfaces of some boulders were covered with the liverworts *Lophocolea minor, L. austrigena* and *Neesioscyphus phoenicorhizus*. The sides of the boulders were covered with the red alga *Hildenbrandia rivularis* and the blue-green alga *Entophysalis rivularis*, and the undersides appeared bare. Larvae were found on the undersides of boulders, in groups, their cases tightly wedged into cracks in the rocks. Species found in association with *R. vernale* included the mollusc *Potamopyrgus antipodarum*, an undescribed flatworm *Dugesia* sp. and larvae of the mayfly *Deleatidium myzobranchia* and of the caddisfly *Hydrobiosis parumbripennis* (Rhyacophilidae).

STEWART ISLAND LOCALITIES

Of the Stewart Island localities, A. G. McFarlane (pers. comm.) writes: "Larvae were found in moderate numbers in small stable streams of average width 0.5–1.0 m. The banks were steep with a good deal of undercutting and moss to the water's edge. Such streams were well shaded and consequently contained much leaf detritus which stained the water light brown. The stream-beds consisted of small- and medium-sized stones and coarse sand. Larvae were found in water of depth 20–30 cm. Except for areas of turbulent water, the flow was slow to moderate. Water temperature was not recorded". There are no chemical data available for water in streams on Stewart Island.

LIFE HISTORY AT WAIKOROPUPU SPRINGS

Life history studies are based on field observations made between September 1970 and January 1972, supplemented by laboratory rearing of individuals at all stages of development.

Eggs: Egg masses were not observed in the field but unfertilised eggs were dissected from a late pupa and fertilised eggs were laid in the laboratory. Eggs are pale orange, spherical and 0.19 mm in diameter. An egg mass of diameter 2.2 mm was sketched 24 hours after the last eggs were laid (Fig. 10). It consisted of a spiral ribbon of 100 eggs, surrounded by clear jelly. Eggs hatched after 21–24 days at 12°C (L/D: 16/8), 46–48 days at 12°C (L/D: 8/16) and about 18 days at 20°C (L/D: 12/12). Eggs did not hatch over an extended period as has been observed in many Plecoptera and Ephemeroptera (Hynes, 1970).

Larvae: Measurements of larval headwidths of 31 specimens indicated there are probably five larval instars. Their approximate headwidths are: first instar, 0.15 mm; second instar, 0.25 mm; third and fourth instars, uncertain; final (fifth) instar, 1.04 mm. The first instar larva with its characteristic long tarsal claws is shown in Fig. 11.

It was not possible to determine from the small collections made at Waikoropupu Springs whether larval growth extended over one or two years. The duration of

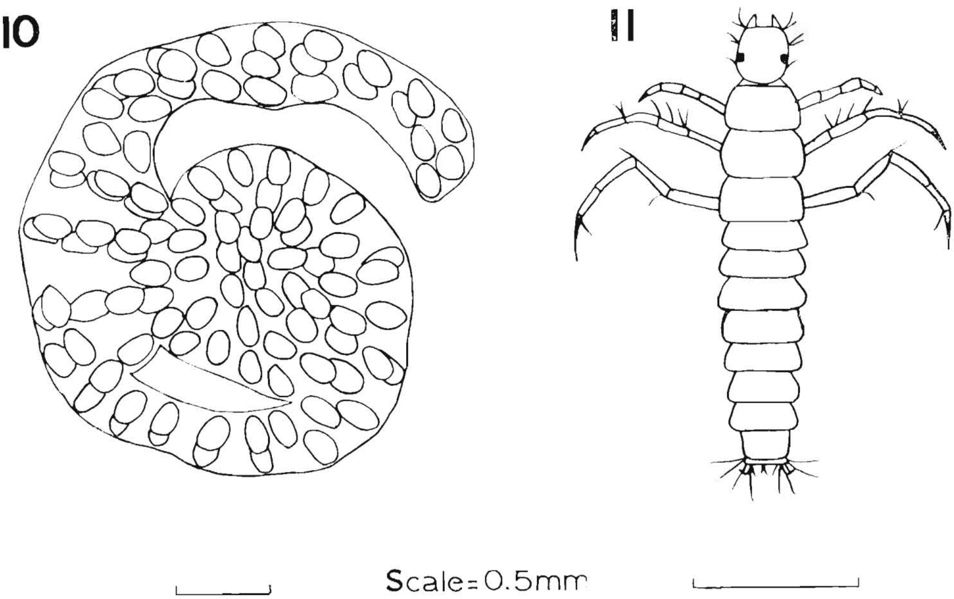
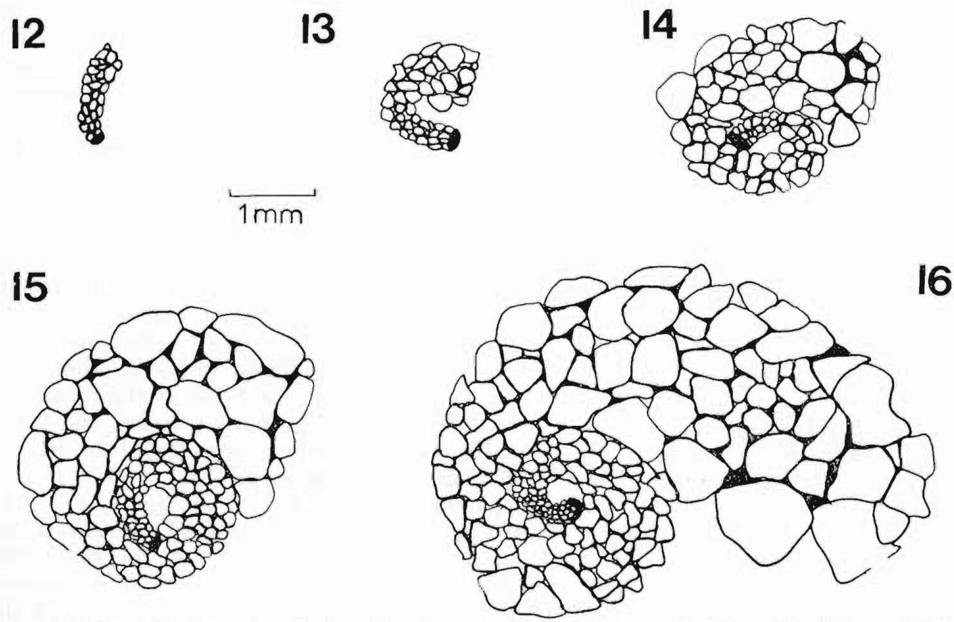


FIG. 10.—*Rakiura vernale,* egg mass. FIG. 11.—First instar larva, dorsal.



FIGS 12–16.—Development of the larval case of *Rakiura vernale*. Fig. 12. Case of first instar larva; Fig. 13. Case of second instar larva; Fig. 14. Case of third instar larva; Fig. 15. Case of fourth instar larva; Fig. 16. Case of final (fifth) instar larva.

early instars is not known, but the final instar lasted at least 82 days in the laboratory at 12°C (L/D: 8/16). Field data suggest that it lasts at least 65 days as no penultimate instars were recovered after the end of April and pupation did not commence until the end of June.

Larval cases: Development of the larval case is shown in Figs 12–16. First instar larvae build straight cylindrical cases of fine sand particles and second instar larvae extend these with coarser sand particles to form a curved case. Third and fourth instar larvae extend these further to form spiral cases which, to the unaided eye, were indistinguishable from those of *Helicopsyche*. However, they were built of coarser sand particles than were those of *Helicopsyche poutini* found in Waikoropupu Springs. Final instar larvae extended the case still further with a distinctive tubular projection of coarse particles. Cases from all localities were mostly white quartz sand cemented with a black secretion.

Pupation: Pupation was preceded by the firm attachment of the larval case to the underside of a large boulder and the closure of the larval case by a silken plate. This plate is translucent, 1.7 mm in diameter, with a central aperture 0.6 mm long. In the laboratory, at 12°C, the pupal stage of one specimen lasted 58–60 days. Field data suggest that it lasts at least 70 days as all final instar larvae had pupated by early July 1971 and first observed emergence took place in mid-September 1971.

Emergence: Four pupae were observed emerging in the laboratory between 1100 and 1600 hr on different occasions. Pupae left their cases and swam to the surface using the first and second pairs of legs which are fringed with hairs and are not prehensible. Pupae remained at the surface of the water, their undulating abdomens curved down. They swam around, trapped in the surface film for at least 10 minutes, and in some cases for longer than 24 hours. This prolonged swimming would probably not occur in the field, as pupae would be vulnerable to fish predation or would be washed far downstream. This may be a result of pupae being disturbed in the laboratory and leaving their pupal cases before being ready to ecdyse (A. G. McFarlane, pers. comm.). Emergence began with the pupal skin splitting down the dorsal side of the head and thorax and the partial emergence of the adult. Sometimes the adults rested at this stage for a few seconds before making a final thrust. The adults then left the pupal exuviae and stood on the surface of the water. The process of emergence lasted only 15 seconds. Adults ran to the edge of the water and using the now prehensile legs, crawled upwards on a twig before resting. There was no period of expansion of the wings and adults were able to fly immediately after emergence.

Adults: Adults were taken in the field from mid-September to early October (18.ix.70–10.x.70 and 10.ix.71–9.x.71). They were seen swarming on manuka and kanuka and, to a lesser extent, on gorse surrounding the Springs. Adults can fly, but generally seem to move about by rapid crawling during the day. Adults were observed to be active in the field when the air temperature ranged from 9°C–21°C. Adults were not observed feeding and individuals kept for up to eight days in the laboratory did not feed on a sugar solution that was offered to them. They were found to be short-lived in the laboratory (maximum adult life 8 days) and in the field, adults were present only from mid-September to early October and hence could not have lived more than 29 days. Late female pupae contained mature eggs and there was no evidence of diapause occurring in adults.

Copulation was observed in the field at 1400 hr on a sunny day (air temperature 9°C). Initially the copulating pair rested on a manuka branch about 50 cm above the ground. After 30 minutes, the pair separated and the two adults were collected and taken to the laboratory where they were placed in an oviposition aquarium. The following day, the female was seen floating on the surface of the water, abdomen undulating, after which it swam down 30 cm to the bottom of the dish where eggs were laid. The spent female lived another 2 days out of the water but all attempts to induce further mating in the laboratory were unsuccessful.

Mortality: Possible predators of *R. vernale* larvae in the Springs include trout (*Salmo trutta*), eels (*Anguilla dieffenbachii* and *A. australis schmidtii*) and larvae of a caddis, *Hydrobiosis parumbripennis* (Rhyacophilidae). Numerous adult *R. vernale* were seen caught in spiders' webs around the edge of the Springs, and fantails (*Rhipidura fuliginosa*), which feed on the wing, almost certainly take them.

Little shelter for adults is available now round the edge of the Springs and substantial numbers of adults died during winds and heavy rain at the end of September 1971. Such conditions, which were more common during the adult flight period of 1971 than 1970, may account for the small numbers of larvae present in 1971–1972 compared to 1970–1971.

DISCUSSION

The life history of *R. vernale* in Waikoropupu Springs is unusual for a caddisfly in that winter is spent as a pupa, emergence takes place very early in spring and the flight period is short. Three other species of caddis that have been studied in Waikoropupu Springs, *viz, Polyplectropus puerilis* McLachlan (Polycentropodidae), *Conuxia gunni* (McFarlane) (Sericostomatidae), and *Zelolessica cheira* McFarlane (Helicophidae) emerge over an extended period in late spring and summer (Michaelis, unpublished data). Other information on the emergence periods of Trichoptera in New Zealand is contained mainly in unpublished theses and, except for Norrie (1969), is restricted to the families Rhyacophilidae, Philanisidae and Leptoceridae. Norrie (1969) recorded the flight periods of many species of Trichoptera near Auckland but results obtained at that latitude may not apply to the higher latitudes of the rest of New Zealand. Winterbourn (1971) recorded only 1 species, *Clistoronia magnifica* (Limnephilidae), emerging in spring soon after ice left the lake in western Canada, and in the United Kingdom, Crichton (1971) found few species of Limnephilidae that emerged in spring. Hickin (1967) recorded 4 species of British Beraeidae emerging in spring and early summer with flight periods of 2–4 weeks.

R. vernale seems to be the first animal known whose distribution is limited to Nelson and Southland although Burrows (1965) recorded many plant species with a similar distribution. In the genus *Blysmopeltis* (Diplopoda), *B. systropha* occurs in Fiordland and *B. figurata* in Nelson-Marlborough-North Canterbury (Johns, 1970). The cockroach *Celatoblatta subcorticaria* is limited to Marlborough-North Canterbury and Fiordland-Southland (including Stewart Island) in the South Island but is also found in the North Island (Johns, 1966).

Distributions of this kind may be the result of Pleistocene glaciations, before which *R. vernale* may have been widespread in the South Island of New Zealand. During the ice advances of the late Pleistocene, its distribution was probably restricted to ice-free areas which Willett (1950) suggests were found in Stewart Island (up to 150 m above sea-level), South East Otago, the Marlborough Sounds and North West Nelson (Fig. 9). As the ice retreated at the end of the Otira Glaciation (Suggate, 1965), water temperatures increased and *R. vernale*, unable to survive in streams with a large variation in water temperature could have found refuge in large, cold springs such as Waikoropupu, where the water temperature, in summer, remained lower. *R. vernale* has also remained in parts of Stewart Island and its outlying islands where water temperatures in well-shaded streams are presumably cool but apparently has not colonised the Southern Alps since the last glaciation perhaps because of the Birch Hill ice advance after the last glaciation (Burrows, 1965). The short flight-period of *R. vernale* and its restricted powers of flight would presumably make recolonisation a very slow process.

There are several records of glacial relicts, notably in the Northern Hemisphere. Bornhauser (1913), Hubault (1927) and Carpenter (1928) all mention springs containing stenothermal coldwater inhabitants which are relicts from glacial periods. Nielsen (1950) discussed the best-known trichopteran example, *Apatania* (= *Apatidea*) *muliebris* (Limnephilidae), a true Arctic relict, found in a few springs in the North European lowlands. Its life history in the cold Rold Kilde (Denmark) is adapted to sub-polar conditions and has persisted in spite of a change to milder conditions. Overwintering occurs as a larva in a pupal case and emergence, egg-laying and growth of larvae take place during the brief summer (Nielsen, 1950). The life history of *R. vernale* in Waikoropupu Springs is not unlike that of *A. muliebris* in Rold Kilde and may be adapted to colder conditions than now exist in and around Waikoropupu Springs.

ACKNOWLEDGMENTS

This work was financed by the Cawthron Institute and forms part of a Ph.D. study in the Zoology Department, University of Canterbury, Christchurch.

I acknowledge the help of Mr K. W. Allison and Mrs E. A. Hodgson in identifying liverworts; Miss H. M. Campbell, the owner of the Springs; Entomology Division, D.S.I.R. in providing constant temperature facilities; Dr E. A. Flint in identifying algae; the Lands and Survey Department, Nelson, in preparing the map; Hydrological Survey, Ministry of Works, Nelson, in measuring water discharge; Mr A. G. Richards in recording climatic data and Dr M. E. U. Taylor in chemical analyses of water samples.

I also thank Mr A. G. McFarlane, Canterbury Museum, for his constant help and encouragement and Drs Vida M. Stout and M. J. Winterbourn for reading the manuscript.

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PART 5

TROPHIC STRUCTURE

INTRODUCTION

Cold springs are comparatively constant physical and chemical environments suitable for investigations of community metabolism. A number of recent studies on cold springs have been concerned with aspects of production ecology such as defining the trophic structure of the springs and determining standing crops, production and energy budgets.

The first major study was carried out by Odum (1957a) who provided comprehensive data on biomass, productivity and energy flow in the large, sub-tropical Silver Springs in Florida. He followed this work with a comparative survey of primary productivity in eleven Florida springs (Odum 1957b). Teal (1957) recorded biomass and energy flow in a temperate cold spring with a large input of detritus. Tilly (1968), working on a cold spring in Iowa, described the food web and standing crop of invertebrates as well as providing an energy budget for the spring. More recently, Wilhm (1970) studied a cold spring ~~near~~ in Tennessee, recording biomass and trophic structure.

This part of the study on Waikoropupu Springs was undertaken to quantify the apparent abundance of plants and invertebrates in the Springs, thus providing a comparison with Silver Springs (Odum 1957a). The trophic structure of the Springs, the biomass at each trophic level and the seasonal changes in the biomass at each trophic level were investigated.

METHODS

The biomass at each trophic level at three sites within Waikoropupu Springs and in the Springs as a whole was estimated.

DRY WEIGHT AND ORGANIC MATTER

For plants, the methods outlined in Part 2 were used. To determine dry weights of animals, ten specimens of a given species and size were selected from several sampling dates. Specimens were removed from alcohol, dried to constant weight at 60°C (4-120 hours) and weighed to the nearest 10 μg. (Up to ten individuals were weighed together for specimens of low weight). No correction was made for weight loss due to preservation before drying and this may have led to an underestimate of invertebrate biomass. Mean weight was calculated for individuals of each size group of each species.

Caddis cases, which usually contained materials (e.g. moss) not produced by the animals, were removed prior to oven-drying. Because of their high inorganic content, ostracod and lamellibranch shells were also removed, but it was not practicable to remove snail shells by hand. Treatment in HCl (1M, 4 hours) to remove the snail shells proved unsatisfactory as it dissolved not only the inorganic, but also some of the organic component of the snail. Instead, all samples of *Potamopyrgus antipodarum* and selected specimens of *Lymnaea columella* of known shell height were rinsed free of alcohol with distilled water and oven dried to obtain total dry weight. The organic matter content was determined as a percentage of dry weight including shell (see below) and the dry weight of snail tissue excluding shell was assumed to be 1.2 times the organic matter content of the snail (from data of Birger 1961 in Winberg 1971).

Conversion factors used for obtaining dry weights from numerical data for each species of animal are recorded in Appendices 11 and 13. Dry weight per unit area on each sampling date was calculated for each species of animal using the standard areas computed for samples at sites 1 and 4 and the actual sampling area for samples at site 7 (see Part 2).

To obtain organic matter content, oven-dried samples of the major species of animal in the Springs (see below) were selected from as many four-weekly samples as possible (usually 4-12). Samples of 0.1-1.5 g for invertebrates, and up to 400 g for vertebrates, were ashed at 500°C for 90 minutes, cooled in a desiccator and reweighed to obtain the weight of ash. Mean organic matter content as a percentage of dry weight was then calculated.

For comparison with other studies, the following factors were used for interconversion of wet weight, dry weight, organic matter and calorific content:

1 g dry weight of animal tissue	=	about 3 g wet weight (Allen 1951)
1 g organic matter of animal tissue	=	about 5.5 kcal (Tilly 1968)

PYRAMIDS OF BIOMASS

Each species was assigned to a probable trophic level using information from the available literature, and laboratory observations where indicated in Table 5.1. Only the major species were considered; that is, those species with a biomass (dry weight) greater than 1% of the total biomass at their probable trophic level.

Pyramids of biomass were constructed at three sites (1, 4 and 7) for two seasons, autumn 1971 (4 April 1971) and spring 1971 (28 November 1971), representing the times when insect biomass was at a minimum and maximum respectively. For those species that showed little variation in biomass throughout the year or variation in biomass that was not seasonal, e.g. bacteria, bryophytes, crustaceans and molluscs, the mean biomass was calculated from as many samples as possible taken throughout the study period. But for plants and animals that showed a significant seasonal change in biomass, e.g. emergent watercress and most insects, values for biomass given by samples taken on 4 April and 28 November 1971 were used. (When no value was available for 28 November 1971, the value for 9 November 1970 was used).

A pyramid of biomass was also constructed for the entire Springs study area, as delimited in Part 1, using values for annual mean biomass of each species. At sites other than 1, 4 and 7, sampling was less intensive and an approximate biomass value for each species was calculated using its abundance index at the site (Appendix 10).

RESULTS

TROPHIC LEVELS

Four major trophic levels were identified in Waikoropupu Springs (Table 5.1). These were termed the Primary Producer (P); Primary Consumer (C_1) (including bacterial feeders, herbivores and detritivores); Secondary Consumer (C_2) (carnivores); and Saprophyte (S) (bacteria and fungi) levels. The term "decomposers", used by Odum (1957a) to include bacteria and detrital-feeding crustaceans, was not used as it was difficult to determine what proportion of the Primary Consumer biomass was supported by autochthonous detritus and what proportion by living plant material. Instead, the term "saprophytes" was employed to include bacteria and fungi.

Table 5.1 shows the most probable trophic level occupied by each species. Eels (*Anguilla australis schmidtii* and *A. dieffenbachii*), trout (*Salmo trutta*) and shags (*Phalacrocorax*

TABLE 5.1: Classification of major species in and around Waikoropupu Springs according to probable trophic level. References used for the classification are given in brackets.

PRIMARY PRODUCERS (P)

Spirogyra sp.
Cratoneuropsis relaxa, *Cyathophorum bulbosum*, *Fissidens rigidulus*
Lophocolea austrigena, *Lophocolea minor*
Juncus microcephalus, *Lemna minor*, *Nasturtium microphyllum*, *Myriophyllum elatinoides*

PRIMARY CONSUMERS (C_1)

Lumbriculus variegatus (Brinkhurst and Jamieson 1971)
Paracalliope karitane (Percival 1932 for *P. fluviatilis*)
Paratya curvirostris (Percival 1932)
Paranephrops planifrons (Percival 1932)
Megaleptoperla diminuta (laboratory observations by the author)
Orthocladiinae (Forsyth 1971)
Conuxia gunni (laboratory rearing by the author)
Zelolessica cheira (laboratory rearing by the author)
Lymnaea columella (laboratory rearing by the author)
Potamopyrgus antipodarum (Percival 1932)
Anas superciliosa (Oliver 1955)
Bos taurus (Van Dyne 1968)

SECONDARY CONSUMERS (C_2)

Dolomedes sp. (Forster 1967)
Polyplectropus puerilis (Hudson 1904)
Psilochorema tautoru (laboratory rearing by the author)
Anguilla australis schmidtii and *A. dieffenbachii* (Cairns 1942)
Salmo trutta (Hopkins 1970a)
Gallirallus australis (Oliver 1955)
Phalacrocorax melanoleucos (Oliver 1955 for other species of *Phalacrocorax*)
Rhipidura fuliginosa (Oliver 1955)

SAPROPHYTES (S)

Bacteria

melanoleucos) probably feed both on primary and secondary consumers but were assigned to the secondary consumer level.

PYRAMIDS OF BIOMASS

a. Sites 1, 4 and 7 (moss, liverwort and watercress)

Biomass per unit area for each species of animal on each sampling date at these sites is shown in Appendix 12. The pyramids of biomass drawn from these data were broad-based and in general there was little difference between pyramids constructed for autumn 1971 and spring 1971 (Fig. 5.1, based on Table 5.2).

At the Producer level, the greatest biomass was at site 7 (watercress). At sites 1 and 4 biomass at the Producer level was similar in autumn and spring 1971 because bryophytes did not show much seasonal variation in biomass. However, the alga Spirogyra sp., which was epiphytic on moss at site 1, was more abundant in autumn 1971 than in spring 1971. A considerable difference in biomass of watercress (site 7) was found between autumn and spring 1971 (1260 and 950 g/m^2 respectively) but some of the autumn increase was above the water surface and not available as a habitat for aquatic invertebrates.

The biomass at the Primary Consumer level was similar at all three sites. The major species in liverwort and watercress was Potamopyrgus antipodarum and in moss, P. antipodarum and Paranephrops planifrons. There was some seasonal variation recorded in total biomass at this trophic level between autumn and spring 1971, due to the seasonal variation in biomass of the insects. At site 1 (moss), the presence of large numbers of insects in spring 1971 resulted in an increase in biomass from 40.6 g/m^2 in autumn to 51.8 g/m^2 in spring. At sites 4 and 7 (watercress and liverwort), mean annual biomass of insects

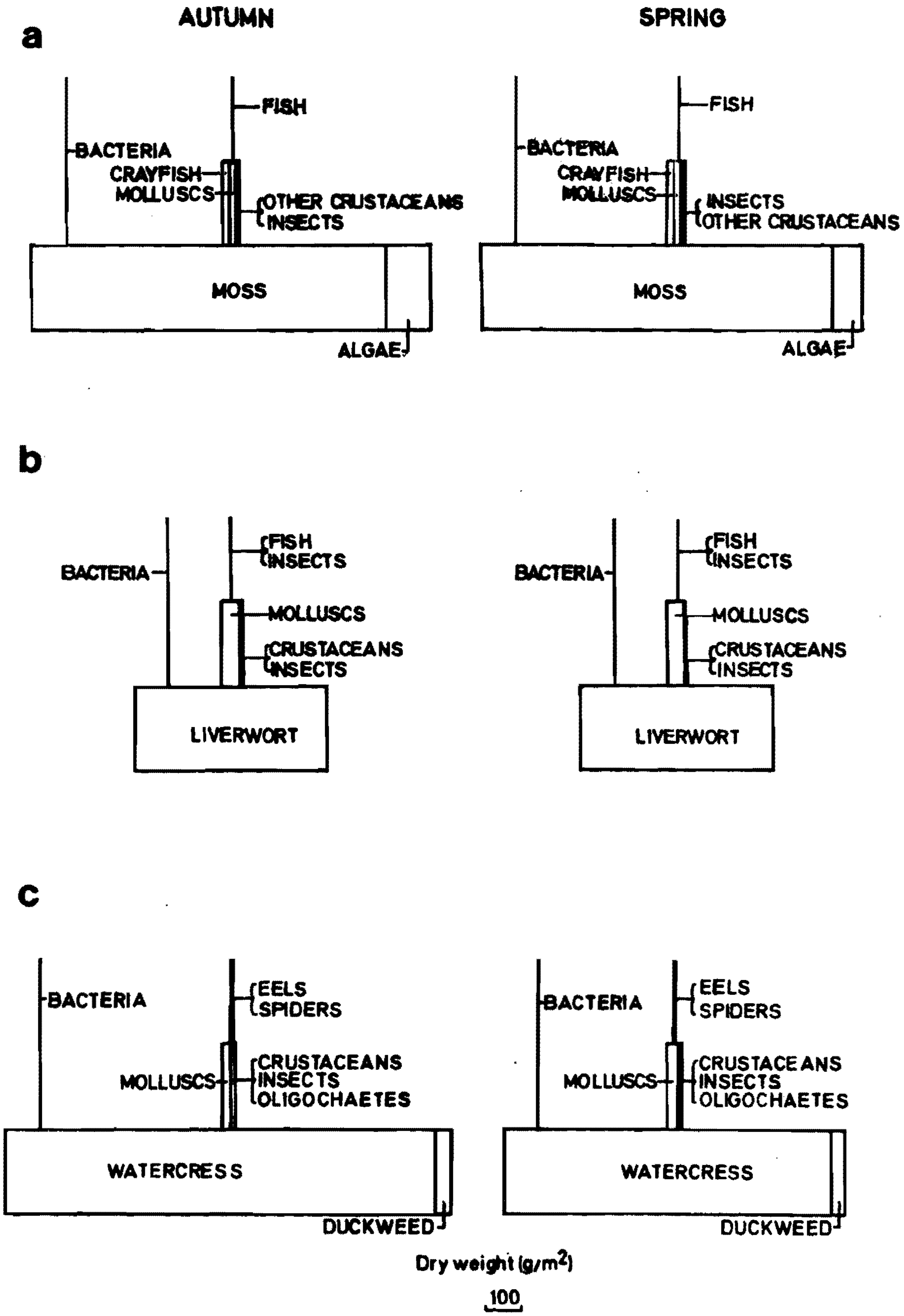

FIG. 5.1: Pyramids of biomass for three sites in Waikoropupu Springs in autumn 1971 and spring 1971. a. site 1 (moss) b. site 4 (liverwort) c. site 7 (watercress).

TABLE 5.2: Biomass of major species of plants and animals at three sites in Waikoropupu Springs in autumn 1971 and spring 1971, arranged according to trophic level. Only species that contribute more than 1% of the biomass of a given trophic level are considered. ND denotes no quantitative data available. For bases of calculation of this table, refer to Appendix 13.

a. site 1 (moss)
b. site 4 (liverwort)
c. site 7 (watercress)

	Component		Biomass (g dry wt/m²) autumn 1971	spring 1971
a.	PRODUCERS			
	Spirogyra sp.		120	90
	Cratoneuropsis relaxa-*Fissidens rigidulus*		1070	1070
		TOTAL	1190	1160
	PRIMARY CONSUMERS			
	Paracalliope karitane		0.4	0.4
	Paratya curvirostris		0.6	0.6
	Paranephrops planifrons		20.8	20.8
	Orthocladiinae		<0.1	0.4
	Conuxia gunni		0.1	4.8
	Zelolessica cheira		<0.1	6.1
	Potamopyrgus antipodarum (excl. shell)		18.7	18.7
		TOTAL	40.6	51.8
	SECONDARY CONSUMERS			
	Psilochorema tautoru		0.20	0.76
	Polyplectropus puerilis		<0.01	0.18
	Anguilla dieffenbachii		0.39	0.39
	Salmo trutta		0.51	0.51
		TOTAL	1.10	1.84
	SAPROPHYTES			
	Bacteria		0.006	0.006
b.	PRODUCERS			
	Lophocolea spp., *Neesioscyphus phoenicorhizus* and *Cyathophorum bulbosum*		570	570
		TOTAL	570	570
	PRIMARY CONSUMERS			
	Paracalliope karitane		1.6	1.6
	Paratya curvirostris		0.2	0.2
	Paranephrops planifrons		4.2	4.2
	Orthocladiinae		<0.1	0.1
	Conuxia gunni		<0.1	1.8
	Zelolessica cheira		<0.1	0.2
	Potamopyrgus antipodarum (excl. shell)		48.2	48.2
		TOTAL	54.2	56.3
	SECONDARY CONSUMERS			
	Polyplectropus puerilis		<0.01	0.51
	Psilochorema tautoru		0.06	1.05
	Anguilla dieffenbachii		0.39	0.39
	Salmo trutta		0.51	0.51
		TOTAL	0.96	2.46
	SAPROPHYTES			
	Bacteria		ND	ND
c.	PRODUCERS			
	Nasturtium microphyllum		1260	950
	Lemna minor		50	35
		TOTAL	1310	985
	PRIMARY CONSUMERS			
	Lumbriculus variegatus		0.3	0.3
	Paracalliope karitane		0.1	0.1
	Paratya curvirostris		3.2	3.2
	Paranephrops planifrons		1.6	1.6
	Megaleptoperla diminuta		0.6	1.8
	Potamopyrgus antipodarum (excl. shell)		32.6	32.6
	Lymnaea columella (excl. shell)		0.2	0.2
		TOTAL	38.6	39.8
	SECONDARY CONSUMERS			
	Dolomedes sp.		0.1	0.1
	Anguilla australis schmidtii		5.5	5.5
		TOTAL	5.6	5.6
	SAPROPHYTES			
	Bacteria		0.05	0.05

was lower and seasonal variation was less marked.

Eels and trout were the major components of the biomass at the Secondary Consumer level. In emergent watercress *Anguilla australis schmidtii* was the most important species but in other areas, large individuals of *A. dieffenbachii* and *Salmo trutta* were the most important components. The spider *Dolomedes* sp. was a minor component of this trophic level at site 7 (watercress) and caddis fly larvae were a small component at sites 1 and 4, showing some seasonal variation in biomass.

Bacteria were assumed to be the only component at the Saprophyte level as the numbers of fungi on aquatic plants were apparently very low (Part 2). The biomass of heterotrophic bacteria that grew under laboratory conditions was higher in watercress (site 7) than in moss (site 1). No data are available for the biomass of bacteria in liverwort (site 4).

b. The Springs study area

Table 5.3 (based on Appendix 14) presents data on dry weight and organic matter per unit area for the major species of plants and animals in the Springs as a whole, as opposed to the three sampling sites dealt with in the previous section. The same species were dominant and the same general relationships held between trophic levels whether results were expressed as dry weight per unit area or organic matter per unit area.

The most noticeable feature of the pyramid of biomass (dry weight) for the entire Springs study area (Fig. 5.2) is that it is very broad-based, for two reasons. Firstly, the major primary producers are macroscopic plants. Secondly, the Springs are almost entirely dependent on photosynthesis within them, rather than on allochthonous detritus, for input of energy, since there is no appreciable inflow from the surrounding land

TABLE 5.3: Biomass of major species of plants and animals in Waikoropupu Springs, arranged according to trophic level. Only species that contribute more than 1% of the biomass of a given trophic level are considered.

Component		Mean biomass (g/m^2)	
		Dry weight	Organic matter
PRODUCERS			
Cratoneuropsis relaxa and Fissidens rigidulus		82	66
Lophocolea spp., Neesioscyphus phoenicorhizus and Cyathophorum bulbosum		104	76
Lemna minor		7	6
Juncus microcephalus		55	47
Nasturtium microphyllum		194	159
Myriophyllum elatinoides		104	93
	TOTAL	546	447
PRIMARY CONSUMERS			
Paracalliope karitane		0.3	0.2
Paratya curvirostris		1.0	0.8
Paranephrops planifrons		3.1	2.1
Conuxia gunni		0.1	0.1
Potamopyrgus antipodarum excl. shell		12.0	10.0
	TOTAL	16.5	13.2
SECONDARY CONSUMERS			
Psilochorema tautoru		0.05	0.05
Anguilla australis schmidtii		0.88	0.82
Anguilla dieffenbachii		0.39	0.33
Salmo trutta		0.51	0.37
	TOTAL	1.83	1.57
SAPROPHYTES			
Bacteria		0.01	0.01

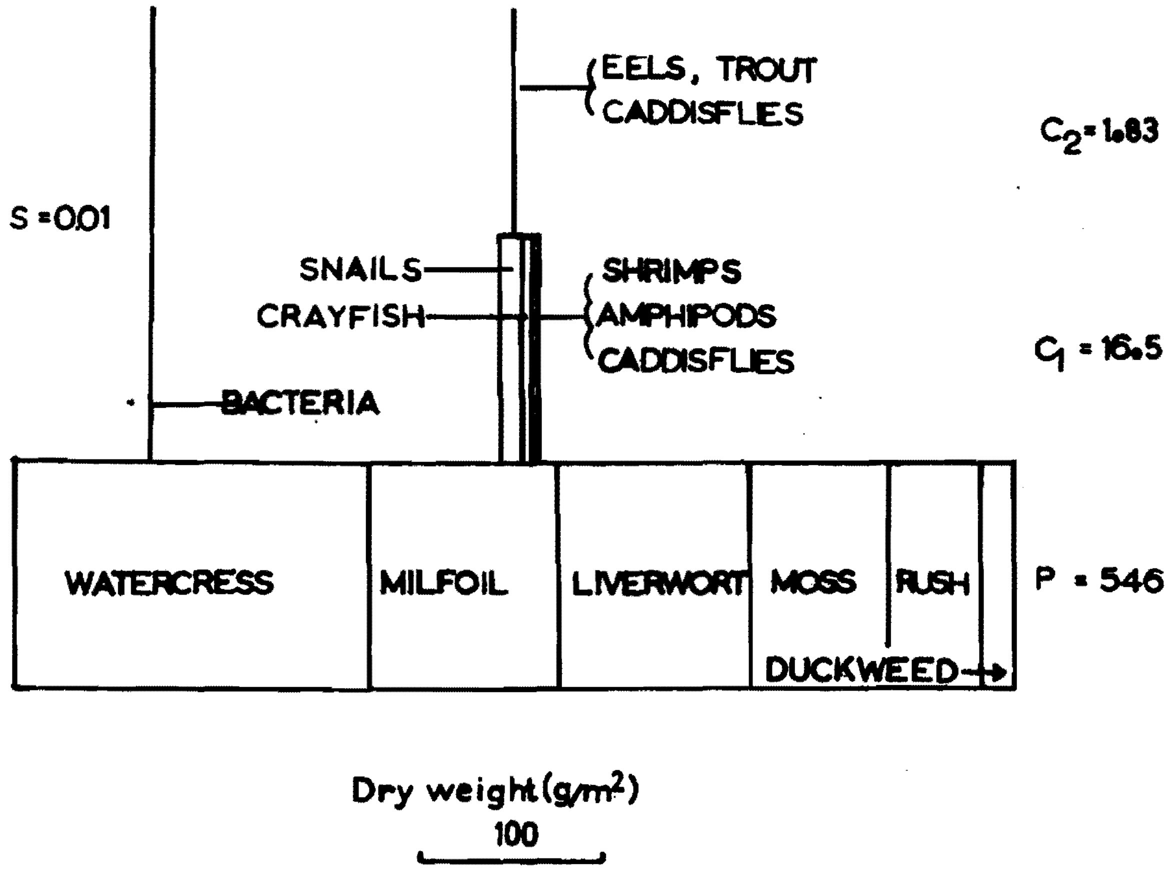

FIG. 5.2: Pyramid of biomass for Waikoropupu Springs. P = Producers, C_1 = Primary Consumers, C_2 = Secondary Consumers and S = Saprophytes.

and little forest surrounding the Springs. In addition, a high water discharge rate and generally moderate to very strong water velocities prevent the accumulation of autochthonous detritus.

There are many important primary producers including five species of bryophytes and four species of angiosperms. The Primary Consumer level is less diverse, its major components being crustaceans (3 spp.), an insect and a mollusc. Organic matter of the snail Potamopyrgus antipodarum contributes more than 75% of the biomass at this trophic level. The Secondary Consumer level is dominated by eels (2 spp.) and a species of trout, with a minor contribution from carnivorous caddis (2 spp.). The Saprophyte level has a very low biomass of bacteria.

Biomass ratios between trophic levels were:

	biomass	
trophic level	dry weight	organic matter
C_1/P	3.0%	3.3%
C_2/C_1	11%	11%

No estimate was made of the biomass of birds and cattle supported by the Springs, but their presence or absence was recorded (Fig. 2.7, Part 3,p.104 and Appendix 7). Sightings of the grey duck (Anas superciliosa) and domestic cattle, which occupy the Primary Consumer level, were not frequent. However, sightings of the little shag (Phalacrocorax melanoleucos), fantail (Rhipidura fuliginosa) and weka (Gallirallus australis), all of which were placed in the Secondary Consumer level, were more frequent.

DISCUSSION

The annual mean biomass of benthic invertebrates (including primary and secondary consumers), averaged over the

Waikoropupu Springs study area, was 16.5 g dry wt/m^2 or 13.2 g organic matter/m^2. These values are similar to those reported for other cold springs. In Silver Springs, the annual mean biomass at the herbivore (Primary Consumer) level was 37 g dry wt/m^2, although only 19 g dry wt/m^2 of this consisted of benthic invertebrates, the remainder being aquatic reptiles and fish (Odum 1957a). In a temperate cold spring in Iowa, the annual mean standing crop of consumers (all invertebrates) was 77 kcal/m^2 (about 14 g organic matter/m^2) (Tilly 1968). A mean standing crop of benthic invertebrates of 7.7 g organic matter/m^2 was measured in a small cold spring in Tennessee over the period April to September (Wilhm 1970). At Waikoropupu Springs, the maximum biomass of invertebrates was found in beds of moss and liverwort; an annual mean biomass of about 45 g dry wt/m^2 occurring in moss and 55 g dry wt/m^2 in liverwort. In a Fissidens (moss) bed near the spring source of a brook in Kentucky, Minckley (1963) recorded a maximum biomass of invertebrates of 8 g/ft^2 (87 g/m^2) wet weight excluding gastropods and decapods or 29 g/ft^2 (315 g/m^2) wet weight including gastropods and decapods. This corresponds to about 50 g/m^2 dry weight excluding shells of gastropods which is similar to that found in Waikoropupu Springs.

The annual mean biomass of benthic invertebrates at Waikoropupu Springs exceeds the few values reported for other running waters in New Zealand. Allen (1951) recorded a biomass of benthic invertebrates in the Horokiri (Horokiwi) Stream of 85-647 mg wet wt/ft^2 (about 0.3-2.3 g dry wt/m^2) and considered this stream typical of many in New Zealand. Hopkins (1970a), working in the Wairarapa region, found a slightly higher standing crop of benthic invertebrates of between 2.6–13.1 g wet wt/m^2 in the Hinau Stream and 11.3–23.0 g wet wt/m^2 in the Hinaki Stream (about 0.9–4.4 and 3.8–7.7 g dry wt/m^2 respectively). The higher biomass of invertebrates at Waikoropupu Springs might result from the stability of the Springs environment, from the low biomass of fish predators (see below) or from differences in sampling methods.

The biomass of fish (eels and trout) in Waikoropupu Springs of about 1.8 g dry wt/m^2 (8 g wet wt/m^2) is lower than that found in other running waters studied in New Zealand e.g. the Horokiri Stream (1.1–3.3 g wet wt/ft^2 or 12–36 g wet wt/m^2, Allen 1951); the Hinau Stream (17–36 g wet wt/m^2, Hopkins 1970a) and the Hinaki Stream (41–117 g wet wt/m^2, Hopkins 1970a). The Springs support a biomass of eels of about 1.3 g dry wt/m^2 (53 lb wet wt/acre) and would be classed by Burnet (1952) as a low yield area (less than 60 lb wet wt/acre). The biomass of fish in Waikoropupu Springs may have been underestimated by the method used, compared to the netting methods of Allen (1951) or the electric fishing of Hopkins (1970a). However, the biomass of fish in the Springs might be low because of several factors: lack of shelter for eels (Burnet 1952); lack of a suitable spawning ground for trout on the western side of the Takaka Valley; and very strong water velocities in the Springs outflow which probably restrict the upstream movement of small fish such as bullies. In the Main Spring, the level of dissolved oxygen (6.6 g/m^3), together with the level of free carbon dioxide (5.8 g/m^3), is just above the limit tolerated by trout (Frost and Brown 1967) but eels (e.g. Anguilla rostrata) are known to tolerate reduced levels of dissolved oxygen (Hill 1969). Birds may also contribute significantly to the biomass of the Secondary Consumer level by feeding on animals in the

Springs, but the extent of their contribution is unknown.

The trophic structure of Waikoropupu Springs is compared with that of other cold springs in the General Discussion.

GENERAL DISCUSSION

Biotopes within the Waikoropupu Springs study area

The distributions of plants and animals in Waikoropupu Springs have been related to substrate type and water velocity (Parts 2 and 3). Where the plant or animal species present on a substrate type in a particular water velocity include characteristic species, the substrate type and water velocity is termed a biotope (Dahl 1908) and the plant and animal species present constitute a biocoenosis (Mobius 1877 cited by Hutchinson 1967). In each biocoenosis the plants can be separated into the following groups: characteristic (faithful or exclusive) species (Poore 1955), indifferent species (Tansley 1946) which occur as often outside as within the biotope and casual species (Tansley 1946) which are found rarely and casually within the biotope. The animals in each biocoenosis can be separated into the following groups: characteristic species (Berg 1948), other numerous species, less numerous species and rare species (Thorup 1966).

Previous work has delimited biotopes in running water solely on the basis of characteristic species of animals (Berg 1948; Thorup 1966). In the biotopes of Berg and Thorup, the plants were considered together with the physical substrate as a "substrate" for the animals. In the present study, however, plants were considered to be part of the biocoenosis associated with the biotope rather than part of the biotope itself.

Table GD.1 lists the major substrate types and water velocities in the study area and shows that each of these could be termed a biotope either because it had characteristic

TABLE GD.2: Major physical, chemical and biological features of 14 cold springs. See text for method of classification. Abbreviations: lat. - latitude; temp. - temperate; sub-t. - sub-tropical; Temp. - Temperature; homoth. - homothermal; heteroth. - heterothermal; v. - very; mod. - moderate; fw - freshwater. N.D. denotes no suitable data available.

Spring	Reference	Lat.	Substrate	Water: Temp. variation	Water: Vel.	Water: Order of discharge	Water: Chem.	Number of biotopes	Dominant component of trophic structure
Waikoropupu Springs, Takaka, N.Z.	Present study	warm temp.	bedrock boulders gravel (silt)	homoth.	v.slight to v. strong	1st	fw	5	autotrophic
Silver Springs, Florida, U.S.A.	Odum (1957a)	sub-t.	silt	homoth.	slight	1st	fw	1	autotrophic
Doe Run, Kentucky, U.S.A. (St.I)	Minckley (1963)	warm temp.	rubble sand (mud)	homoth.	N.D.	1st	fw	N.D.	autotrophic
Rold Kilde, Denmark	Nielsen (1942) Berg (1951 Thorup (1963, 1966)	cool temp.	stones N.D.	homoth.	N.D.	N.D.	N.D.	5	N.D.
Ravn Kilde, Denmark.		cool temp.	stones gravel N.D.	homoth.	slight mod.	3rd	N.D.	5	N.D.
Lille Blaakilde, Denmark		cool temp.	N.D.	homoth.	strong	3rd	N.D.	5	N.D.
Tyee Springs, Washington, U.S.A.	Davidson & Wilding (1943)	cool temp.	gravel mud	homoth.	"slow"	N.D.	fw	N.D.	N.D.
Lander Springbrook, New Mexico, U.S.A.	Noel (1954)	warm temp.	rubble	homoth.	mod.	N.D.	mineral (mesohaline)	N.D.	N.D.
Root Spring, Massachusetts, U.S.A.	Teal (1957)	warm temp.	mud	homoth.	N.D.	3rd	N.D.	N.D.	heterotrophic
Cone Spring, Iowa, U.S.A.	Tilly (1968)	warm temp.	pebbles sand	heteroth.	N.D.	3rd	fw	1	autotrophic/ heterotrophic
Morgan's Creek, Kentucky, U.S.A. (St.I)	Minshall (1967, 1968)	warm temp.	bedrock boulders	heteroth.	slight	3rd	fw	N.D.	heterotrophic
springbrook, Tennessee, U.S.A. (St.I)	Stern & Stern (1969)	warm temp.	bedrock marl	heteroth.	v.slight slight mod.	N.D.	fw	N.D.	N.D.
spring, Tennessee, U.S.A. (St.I)	Wilhm (1970)	warm temp.	mud	N.D.	N.D.	3rd	fw	N.D.	N.D.
Avonhead Springs, Christchurch, N.Z.	Marshall (1973)	warm temp.	mud	homoth.	mod.	*3rd	fw	N.D.	N.D.

* incorrectly given in original paper

species of plants and/or animals or because it lacked any characteristic species of plants and animals. There were five biotopes: boulders in a very strong water velocity; boulders in a moderate to strong water velocity; stable gravel in a slight to strong water velocity; unstable sand and gravel in a slight to strong velocity; and silt and water of very slight velocity. The biotopes delimited by characteristic plant and animal species were similar, but it was simpler to delimit biotopes on the basis of plant species as their distributions had easily recognisable boundaries. Although the biotopes were most clearly defined in shallow water, they extended into the deeper parts of the Springs.

The five biotopes and associated biocoenoses can be compared:

Biotope 1. Bedrock and boulders in a very strong water velocity had no characteristic plant species as the algae _Hildenbrandia rivularis_ and _Entophysalis rivularis_, dominant in this biotope, were classed as indifferent since they were also found in biotope 2 (below). The biotope was characterised by the absence of bryophytes and angiosperms, which are common on stable substrates in the rest of the study area. The fauna in this biotope was moderately abundant and included two characteristic species, the triclad _Dugesia_ n.sp. and the mayfly _Deleatidium myzobranchia_.

Biotope 2. Boulders in moderate to strong water velocity, and a small area of bedrock in a slight water velocity, had seven characteristic species of plants, of which six were bryophytes and one was a green alga (_Spirogyra_ sp.) epiphytic on a bryophyte. There were also two indifferent species of algae (see biotope 1) and another four species of bryophytes which were casual species in this biotope. The fauna on boulders in shallow water was very abundant and there were two characteristic species, Conuxia gunni and Zelolessica cheira (both trichopteran larvae with cases). One of these species, Z. cheira, uses the bryophytes for case-building materials. No characteristic species of animals were associated with bedrock and slight water velocity (Table GD.1) perhaps because bedrock was found only at depth 4.3 m, where the fauna was limited in species.

Biotope 3. A substrate of stable gravel in slight to very strong water velocity had three characteristic plant species, all angiosperms rooted firmly into the substrate and submerged, at least in winter (see Part 2). Two of the three species of angiosperms were introduced to New Zealand. The biotope had no characteristic species of animals but it supported a moderately abundant fauna of species widespread in the Springs.

Biotope 4. A substrate of unstable gravel represented nearly one-quarter of the area of the Springs but had no characteristic plant and animal species and the fauna was not abundant.

Biotope 5. Silt and water of very slight velocity had two characteristic species of plants of which Nasturtium microphyllum (watercress) was dominant. Associated with this was an abundant fauna including four characteristic species of invertebrate: two species of crustaceans, an oligochaete and a gastropod. It is interesting that two of the characteristic species of animals on introduced watercress were also introduced.

The biotopes in Waikoropupu Springs may be compared with those in cold springs in Denmark. After a study of three cold springs (Lille Blaakilde, Ravnkilde and Rold Kilde), Thorup (1966) concluded that their fauna did not comprise an ecological unit or community but that the spring was a mosaic of smaller biotopes (substrates), the spring fauna being composed of different communities associated with these substrates, as was found in Waikoropupu Springs. Thorup (1966) recognised five biotopes, two of which are similar to those in Waikoropupu Springs, namely stony bottoms (biotope 1) and areas of moss (biotope 2).

The stony bottom in both Rold Kilde and Ravn Kilde was characterised by the mayfly Baëtis rhodani and the filter-feeding dipteran Simulium ornatum (Thorup 1963). It is interesting that a similar substrate in Waikoropupu Springs was also characterised by a species of mayfly but filter-feeders were not found in Waikoropupu Springs presumably because there was insufficient particulate organic matter in the water to serve as a food supply.

The mosses in Ravn Kilde were not identified by Nielsen (1942) or Thorup (1966) but were characterised by the presence of the psychodid Pericoma blandula (Thorup 1963). Water velocity in the beds of moss in Ravn Kilde was only 10-20 cm/s (slight) (Nielsen 1942) whereas in the beds of moss in Waikoropupu Springs it was moderate. Psychodid larvae were not found in Waikoropupu Springs but the larva of a species of Psychodid is sometimes found in moss and algae in streams in New Zealand (Pendergrast and Cowley 1966). No data are available on the water velocities in which this species occurs.

The third of Thorup's biotopes - swampy border areas - was similar to the biotope of silt and water of very slight velocity near the edge of Waikoropupu Springs. In the Springs, this biotope was dominated by watercress. No details were available on the species of plants found in the swampy border areas of the Danish springs. The remaining biotopes of Thorup's springs - hygropetric areas and areas covered in dead beech leaves - were not present in Waikoropupu Springs. The latter biotope would not be expected in the Springs because the forest that once surrounded the Springs has been cleared.

No other studies have determined the biotopes and biocoenoses within cold springs but studies have been made of springs that contained a single plant and animal community.

Silver Springs, Florida, is a cold spring of discharge comparable to that of Waikoropupu Springs. Ninety-four percent of the area of Silver Springs consisted of beds of the eel-grass, *Sagittaria lorata*, and associated *aufwuchs* on a substrate of *gyttja*. Differences in the density of various species of Trichoptera occurred throughout the springs, apparently influenced by water velocity; but Odum (1957a) provided no evidence that there were differences in the species composition of invertebrates within the *Sagittaria* beds. Silver Springs thus contained a single plant and animal community and could be considered a single biotope, in contrast to the five biotopes in the present study. It is possible that the 6% of these springs not covered by *Sagittaria* beds contains one or more biotopes. The red alga *Thorea* sp. was restricted to the spring vents (Whitford 1956) and several species of aquatic angiosperm (e.g. *Najas guadalupensis* and *Pistia stratiotes*) were restricted to the edge of the spring. However, insufficient data are available to delimit biotopes and biocoenoses other than that of *gyttja* with *Sagittaria lorata*.

Cone Spring, Iowa, had a substrate of fine to coarse sand with pebbles (Tilly 1968) and contained three species of angiosperms, two of which were emergent and one free-floating.

Because the seven species of invertebrates used as indicator species were very evenly distributed (Tilly 1968), Cone Spring, unlike Waikoropupu Springs, could be considered a single biotope.

Thus some cold springs consist of a single biotope while others contain several biotopes. The number of biotopes in the spring is related to the diversity of its substrate types. However, the concept of biotopes should be used with caution. Biotopes emphasize differences between areas on the basis of characteristic species rather than emphasizing similarities because of species common to several areas (Berg 1948).

Waikoropupu Springs as an ecological unit

Studies of other cold springs and their springbrooks have shown that the spring as an ecological unit includes not only the spring itself but extends for some distance below the source. Pennak (1953) stated that this distance is 10 m to 500 m below the source depending on local conditions, but his figures seem to apply only to springs of small discharge. Morgan's Creek, Kentucky, issues from a spring source with a modal discharge of 0.007 m^3/s. Cold stenotherms extend to only 25 m below the source but the spring and Creek can be considered a "single community type" which reaches its maximum development 300 m below the source of the Creek (Minshall 1968). Noel (1954) studied a small springbrook of unspecified discharge in New Mexico and found three species of invertebrate largely restricted to an area which extended for only 15 m below the source. However the spring water with its distinctive temperature and chemistry extended for 77 m below the spring source

Springs with a larger discharge result in larger ecological units. The upper 3/4 mile (1.2 km) of Silver Springs, Florida (total discharge 19 m^3/s) is remarkably uniform, with beds of Sagittaria lorata and aufwuchs, and may be termed an ecological unit of 18.5 acres (7.5 ha) (Odum 1957a). Minckley (1963) studied Doe Run, Kentucky, which originates in a spring of normal discharge 20-40 cusecs (0.6-1.1 m^3/s) and found that the transition zone from the faunal assemblages characteristic of the spring to those characteristic of the downstream zone occurred at a station between 1.7-2.1 miles (2.7-3.4 km) below the spring source.

The study area in Waikoropupu Springs was restricted to the region of the vents and immediately below the vents and thus included only the deep part of the Springs (Fig. 1.4) and none of the Springs outflow (Frontispiece). It is apparent that the area studied is only part of a larger ecological unit which probably includes the auxiliary springs, Fish Creek, Waikoropupu Springs and the outflow of the Springs as far downstream as the confluence of the Springs outflow and the Waikoropupu River (0.75 km below the spring source), for the following reasons.

An eroding substrate and moderate to very strong water velocities extend downstream as far as the confluence of the Waikoropupu and Takaka Rivers and the clarity of the water is high down to this point. As far downstream as its confluence with the Waikoropupu River, the Springs water is rich in calcium and low in dissolved oxygen. In contrast, the Waikoropupu River above this confluence is only moderately rich in calcium (Ca^{2+} = 22 g/m^3, M.E.U. Taylor, pers. comm.) and fully saturated with dissolved oxygen (100%, 8 October 1971).

At least two species of aquatic invertebrate are common to Fish Creek, Waikoropupu Springs and the Springs outflow but are absent from the Waikoropupu River. They are Dugesia n.sp. (Tricladida), a phreatic form, and Rakiura vernale (Trichoptera), a possible glacial relict (see Part 4).

In addition, the catchment area (Bormann and Likens 1967; Likens 1972) and underground containing beds should be included as part of the Waikoropupu Springs system, although they have not been mentioned in previous studies of cold springs. Together they provide water, nutrients and organic matter to the Springs. The catchment area of Waikoropupu Springs has not been clearly defined but probably includes an area of 120 sq. miles (310 km^2) in the Upper Takaka Valley (Henderson 1928); little is known of the extent of the containing beds.

Comparison of Waikoropupu Springs and Silver Springs

The only cold spring of similar discharge which can be compared with Waikoropupu Springs is Silver Springs (Odum 1957a). Water discharge, light transmission and water chemistry are very similar in the two springs but water temperature and water velocity are different. In Waikoropupu Springs, the water temperature is 11.7°C and water velocities are generally moderate to very strong whereas in Silver Springs, the water temperature is 22.2°C (Ferguson et al 1947) and water velocities are slight to moderate.

At the Producer trophic level, Waikoropupu Springs was a mosaic of plant species (algae, bryophytes and angiosperms), in part reflecting the mosaic of substrates and water velocities in the Springs. In contrast, Silver Springs consisted of an extensive carpet of Sagittaria lorata and associated aufwuchs on a uniform substrate of gyttja. Algae were not a significant component of the annual mean biomass at Waikoropupu Springs, in contrast to Silver Springs, as the algal species in Waikoropupu Springs were present at a low biomass in summer and declined markedly in winter. The base of the pyramid of biomass was larger in Silver Springs (809 g dry wt/m^2) than in Waikoropupu Springs (546 g dry wt/m^2), which might be related to a number of factors, including the higher temperature of Silver Springs, the lower water velocities and hence greater accumulation of silt as a substrate in Silver Springs, and the large area (28%) of Waikoropupu Springs that had an unstable substrate without bryophytes or angiosperms.

Total biomass of the Primary Consumer trophic level at Waikoropupu Springs (16.5 g dry wt/m^2) was less than that at Silver Springs (37 g dry wt/m^2). All the major invertebrate components of the Primary Consumer trophic level belonged to the same groups in Waikoropupu and Silver Springs and included Decapoda, Diptera, Trichoptera and Gastropoda. In addition, primary consumers of Silver Springs included small fish and aquatic reptiles with a generation time of greater than one year, allowing accumulation of biomass from year to year. In Waikoropupu Springs, small fish were not usually present, perhaps because of the very strong water velocities and lack of shelter, and aquatic reptiles are not found in New Zealand.

Although the Secondary Consumer level had similar components in both Springs (mainly fish), the Tertiary Consumer level was not well developed in Waikoropupu Springs perhaps because of the lack of small fish as a suitable food for tertiary consumers (Part 5, p.116).

The pyramids of biomass for both Springs are a similar shape and ratios of biomass (dry weight based on annual mean values) between trophic levels are:

	Waikoropupu Springs	Silver Springs (Odum 1957a)
Primary Consumers/ Producers	3.0%	4.4%
Secondary Consumers/ Primary Consumers	11%	31%
Tertiary Consumers/ Secondary Consumers	-	14%

The most obvious difference between the two springs is the much lower Secondary Consumer to Primary Consumer ratio at Waikoropupu Springs compared to Silver Springs. This may result from the low biomass of secondary consumers at Waikoropupu Springs, the reasons for which were discussed in Part 5.

Although the concentration of particulate organic matter in the Waikoropupu Springs outflow was not measured, the discharge rate of the Springs is so high that even a low concentration of particulate organic matter in the outflow could result in a large annual loss of organic matter. This is the case at Silver Springs where loss of organic matter as macrophytes is insignificant when compared to loss as particulate matter, which is exported at a concentration of 0.6-0.9 ppm (g/m^3) and is 12% of the total production of the Springs (Odum 1957a).

The similarity of many physical and chemical features of Waikoropupu and Silver Springs may be responsible for the similarity of some biological features, such as the species composition of epiphytic algae, the invertebrate components of the Primary Consumer trophic level, the broad-based pyramids of biomass and limited seasonal changes in the plant and animal species. The differences in substrate and water velocity between the springs may account for the single biotope with a fine substrate and one associated species of angiosperm in Silver Springs and five biotopes, four of which have a coarse substrate, and many species of bryophytes and angiosperms in Waikoropupu Springs.

Cold springs in general

Waikoropupu Springs can be compared with 13 other cold springs with respect to its general physical and chemical features, the plants and animals present, and its trophic structure (Table GD.2).

Most of the studies of cold springs have been on springs located in warm temperate and cool temperate latitudes (between 33° and 46° latitude, except for the Danish springs at 57°N). The sub-tropical Silver Springs (28°N) is the exception. The difference in latitude, and hence annual solar radiation, between these cold springs is therefore not considered here as a factor affecting the species of plants and animals present. However, the magnitude of seasonal changes in light energy is also determined partly by the latitude of the spring; being greater at higher latitudes, and seasonal changes in light energy may be important in bringing about seasonal changes in the plant and animal species in cold springs (Parts 2 and 3).

Water temperatures for the heterothermal cold springs varied between 5-18°C (Cone Spring), 9.8-14.0°C (Morgan's Creek) and 11.2-15.8°C (unnamed spring of Stern and Stern). In homothermal springs water temperature varied less than 1 C° about the mean and water temperatures of all these springs, except Silver Springs (22°C) and Lander

TABLE GD.1: Biotopes and biocoenoses in Waikoropupu Springs. Substrate type and water velocity (from Part 1); area (from Table 2.6); characteristic plant species (from Table 2.5); characteristic animal species and other numerous animal species (from Table 3.5). An asterisk denotes a species introduced into New Zealand.

Biotope		Biocoenosis		
Substrate type and water velocity	Area as % of total area of Springs	Characteristic plant species	Characteristic animal species	Other numerous animal species
bedrock and boulders - very strong	about 5	none	Dugesia sp. Deleatidium myzobranchia	Potamopyrgus antipodarum
bedrock - slight	28	Spirogyra sp. Cratoneuropsis relaxa Cyathophorum bulbosum Fissidens rigidulus Lophocolea austrigena Lophocolea minor Neesioscyphus phoenicorhizus	none	Paracalliope karitane Potamopyrgus antipodarum
boulders - moderate to strong			Conuxia gunni Zelolessica cheira	Paracalliope karitane Polyplectropus puerilis Psilochorema tautoru Potamopyrgus antipodarum
gravel - slight to strong	26	*Juncus microcephalus Myriophyllum elatinoides *Nasturtium microphyllum (submerged)	none	Paracalliope karitane Potamopyrgus antipodarum
unstable sand and gravel - slight to strong	about 23	none	none	Potamopyrgus antipodarum
silt and water with very slight	16	*Nasturtium microphyllum (emergent and floating) Lemna minor	*Lumbriculus variegatus Herpetocypris pascheri Tropocyclops prasinus *Lymnaea columella	Paracalliope karitane Paraleptamphopus sp. Megaleptoperla diminuta Potamopyrgus antipodarum

Springbrook (18°C), were constant at between 7.5°C and 13.7°C. Water temperature was therefore not considered a major variable between springs.

These cold springs all discharged water that could be termed freshwater except for Lander Springbrook which discharged mineralised water that was mesohaline (Whitford 1956). It would be desirable to further classify the freshwater springs according to their chemical characteristics likely to be of biological importance: dissolved gases (particularly oxygen and carbon dioxide), dissolved salts (particularly the levels of calcium, nitrate and phosphate ions), and dissolved and particulate organic matter, but insufficient data are available.

Some biological features of cold springs could be related to their physical and chemical features such as substrate type and water chemistry. Whitford (1956) studied the species composition of algae in aufwuchs in Florida springs and was able to relate this to the water chemistry of the springs, with four algal associations related to four water chemistry types. Much further work is needed to extend such a study to cold springs in other parts of the world. No comparison of the algae in New Zealand cold springs could be made as Waikoropupu Springs was the only cold spring in which the algae were studied. It is interesting that the epiphytic algae in Waikoropupu Springs had two species and four genera in common with the aufwuchs in 12 hard freshwater springs in Florida (Whitford 1956). The present study did not attempt to relate the species of benthic algae, higher plants or animals found in the cold springs to the chemistry of the spring water as there were insufficient data.

On the other hand, the higher plants in cold springs could be related to the substrate type of the spring which was the most obvious difference between the springs. A few cold springs did not have a uniform substrate throughout the source area. Nonetheless, two major substrate groups were evident - coarse substrates of bedrock, boulders, rubble and stones (found in seven springs) and fine substrates of silt or mud (found in five springs). No data were available for Lille Blaakilde. An intermediate substrate group of gravel, pebbles or small stones was not well represented in the cold springs studied except for parts of Waikoropupu Springs, Ravn Kilde, Tyee Springs and Cone Spring.

A coarse substrate in a cold spring was characterised by a growth of submerged bryophytes. In the North American and Danish springs, these bryophytes were always mosses: e.g. a substrate of marl on bedrock, at station I of Stern and Stern's springbrook, was colonised by Fontinalis antipyretica; a lime-stone slab with boulders at station I (source) of Morgan's Creek had a growth of an unspecified moss; rubble at station I (source) of Doe Run was colonised by Fissidens julianus; a substrate, presumably stony though not described, was overgrown by unspecified mosses in Lille Blaakilde, Rold Kilde and Ravn Kilde. In the New Zealand springs, Waikoropupu and Western Springs, liverworts were present as well as mosses. The reason for the presence of aquatic liverworts in these two New Zealand cold springs is not known.

A substrate of mud and silt, which characterised part or all of seven of the fourteen cold springs studied, was colonised by rooted angiosperms which were emergent in shallow water and submerged in deeper water. In calm water, free-floating angiosperms with associated algae developed. For example, in the Avonhead Springs, a fine substrate was colonised by Callitriche stagnalis and Nasturtium microphyllum; in Silver Springs, a substrate of silt was colonised by the submerged eel-grass Sagittaria lorata.

Thus the kinds of higher plants found in sub-tropical and temperate cold springs could be directly related to the substrate type in the spring.

A comparison was made of the faunas of the cold springs studied. It was found that the animals, when arranged in taxonomic groups, could not be related to substrate type; water temperature, velocity or chemistry; nor to the type of plants present in the cold springs. The comparison might be better if the animals were grouped on the basis of ecological type (Thorup 1966) or ecotope (Whittaker, Levin and Root 1973) rather than on taxonomic groupings. A concept similar to that of plant growth forms, which were useful in the present study, is needed. Until such a concept is developed and all species found in cold springs can be classified according to ecological type, no further comparison of spring faunas is possible.

The trophic structure of two cold springs was compared by Phillipson (1966). He noted that in Root Spring most of the food eaten by primary consumers entered the system as plant debris, whereas in Silver Springs, most of the primary consumers' food was produced within the system by the primary producers. This comparison suggested that cold springs could be classified according to the proportion of energy input to the system from photosynthesis within the spring compared to that from detritus originating outside the spring, i.e. the extent of the auto-trophic component of the system compared to the heterotrophic component. At the source of the springs of largest discharge and area i.e. Waikoropupu Springs, Doe Run, Silver Springs and other Florida springs (Odum 1957b) the energy input was almost entirely derived from photosynthesis by algae, bryophytes and higher plants. In these large springs, detritus from terrestrial vegetation was present only around the edges of the springs and the high rate of water discharge prevented its accumulation.

Two of the three smaller cold springs studied, Root Spring and Morgan's Creek (Minshall 1967), were dependent on allochthonous detritus for most of their energy input (80% and more than 69% respectively). The third spring, Cone Spring, was dependent on allochthonous detritus for 46% of its energy input. In all three springs, detritus was in the form of leaves, twigs and fruit of deciduous trees and shrubs surrounding the springs. Data are not available for any other small cold springs, but the abundance of dead beech leaves as a substrate type in the Danish cold springs suggests that some of their energy input must be from allochthonous detritus.

Methods of classifying springs

Previous methods of classification of springs have used water temperature (Tuxen 1944), water discharge (Meinzer 1927), water chemistry (Whitford 1956) and spring type (see below).

The present study has shown the importance, from a biological point of view, of the following components of a spring: location, substrate, water temperature, water velocity, water discharge and water chemistry; and these features should be considered in classifying a spring. Existing methods of classification of springs according to water temperature and water discharge should be retained but spring type should be rejected as a method of classification.

Spring type (limnocrene, rheocrene or helocrene) has been widely used as a method of classification of springs (Bornhauser 1913; Thienemann 1925; Carpenter 1928; Tuxen 1944; Hesse et al 1951; Noel 1954; Teal 1957; Stern and Stern 1969). The limnocrene, rheocrene and helocrene classifications of these authors give an approximate indication of residence time of water at the spring source and provide a limited amount of data on depth and width of a spring. Carpenter (1928) included, as well, a description of the substrate of the spring, describing a typical limnocrene as having a basin lined with mud and a rheocrene as having a stony or sandy basin. Her descriptions have been overlooked by subsequent authors and, in any case, are of limited application. Using Carpenter's description, it would be difficult to classify a spring such as Waikoropupu with its large basin and coarse substrate. Thus, spring type provides little direct information on the physical features of the spring.

Methods of classification of springs according to substrate, water velocity, water chemistry and location are now proposed.

The suggested method of classification of a spring according to substrate type includes two aspects of the substrate:

(a) The type of substrate present, e.g. bedrock, boulder, coarse sand (Wentworth's classification, slightly modified, in Welch 1948).

(b) Uniformity and distribution of substrate. Whether a single substrate type or several substrate types are present and in the latter case, the distribution of substrate types.

In describing the water velocities encountered in a spring, the classification of Berg (1943) could be used, i.e. very slight, slight, moderate, strong and very strong.

Spring waters should be termed fresh if they contain less than 300 g/m^3 of total dissolved solids and water containing total dissolved solids appreciably in excess of this value should be termed mineralised (Peterken 1967). Whitford's (1956) classification of mineralised water in Florida needs to be extended to cover all types of mineralised water found in New Zealand and elsewhere.

A suitable classification of springs according to latitude could class them as equatorial (0^o to 10^o), tropical (10^o to $23\frac{1}{2}^o$), sub-tropical ($23\frac{1}{2}^o$ to 30^o), warm temperate (30^o to 45^o), cool temperate 45^o to 66^o) or polar (66^o to 90^o).

The present study concludes that there are six physical and chemical features which should be used to classify a spring. They are listed with their reference as follows:

Feature		Reference
latitude		Present study
substrate	- type	Wentworth's classification in Welch (1948)
	- uniformity and distribution	Present study
water temperature		Tuxen (1944)
water velocity		Berg (1943)
water discharge		Meinzer (1927)
water chemistry		Whitford (1956), Peterken (1967) and present study

IDEAS FOR FUTURE RESEARCH

Because Waikoropupu Springs provide an environment of constant water temperature and chemistry, it would be interesting to investigate the relationship between the level of irradiance, dependent largely on depth, and rates of photosynthesis of aquatic plants. Rates of photosynthesis of plants from Waikoropupu Springs could be compared under different levels of illumination in the laboratory and related to field conditions. To ensure that the experimental conditions of illumination apply to those in the field, more detailed measurements of irradiance at different depths in the Springs on a daily and seasonal basis are needed.

The depth to which watercress (*Nasturtium microphyllum*) grows in Waikoropupu Springs (6.5 m) is remarkable. It would be valuable to compare the leaf and chloroplast structure and levels of chlorophyll of this plant growing at different depths.

The method of monitoring changes in the concentrations of oxygen and carbon dioxide as water flows over the submerged plants (Owens 1969) could be used to estimate the total primary productivity of submerged plants in Waikoropupu Springs. The present study area would need to be extended downstream to at least the gauging site.

The Springs provide a suitable area in which to relate the distribution of invertebrates to substrate, water velocity and depth. Further studies on the distribution of invertebrates could investigate the animal assemblages of the rest of the Project Aqua site, and determine whether the animal assemblages of the present study are still valid when juveniles are considered. To achieve these aims, sampling should be extended both in the number of sites sampled and in the area sampled at each site.

Studies of the life histories of the invertebrates in Waikoropupu Springs are particularly interesting because of the constant water temperature. Although some preliminary investigations form part of the present study, additional work on the life histories of invertebrates in the Springs is needed with regard to the eggs and juveniles of most species and the emergence and flight periods of the insects. With more detailed background information, experimental work on the control of life histories in an environment of constant temperature could be planned.

PLACEMENT OF COLLECTIONS

Collections of algae, bryophytes and higher plants from the cold springs studied have been deposited with the Botany Division, D.S.I.R., Christchurch. Collections of aquatic invertebrates from the cold springs are in the Zoology Department Museum, University of Canterbury, Christchurch. A collection of insects from Waikoropupu Springs has been deposited with the Entomology Division, D.S.I.R., Auckland and the specimens of *Rakiura vernale* (Trichoptera) have been deposited with the Canterbury Museum, Christchurch.

SUMMARY

1. (a) The present study investigated, by SCUBA diving, the physical, chemical and biological features of Waikoropupu Springs, the largest cold springs in New Zealand and one of the largest in the world.

(b) The Springs have a maximum depth of 6.9 m and a mosaic of substrate types (bedrock, boulders and gravel). The temperature of the Springs water is constant at 11.7°C. Water velocities are generally moderate to very strong, and average water discharge is about 11 m^3/s. Mean holding time for water in the Springs is 3.8 mins.

(c) The Springs water flows from an artesian basin in Arthur Marble and is low in dissolved oxygen. Unpublished chemical analyses by M.E.U. Taylor show that the water is hard, with a high specific conductivity.

(d) The major variables within the study area are substrate, water velocity and depth since water temperature and chemistry are essentially uniform throughout the area.

(e) Light is the major seasonal variable in the Springs as water temperature is constant all year round and water chemistry, discharge, and hence velocity, are stable with time.

(f) Information on water temperature, discharge and chemistry is provided for five other cold springs in New Zealand.

(g) A system of classification of cold springs, based on published studies of 13 cold springs and proposed from a biological point of view, rejects spring type (limnocrene, rheocrene and helocrene) but includes latitude, substrate, water temperature, water velocity, water discharge and water chemistry.

2. (a) The vegetation in Waikoropupu Springs and in five other N.Z. cold springs is described. Aquatic plants in Waikoropupu Springs include 16 species of algae, 10 species of bryophytes (including three species of liverworts) and five species of angiosperms.

(b) It was possible to relate the distribution of plant species in the Springs to substrate type and water velocity and there were plant species characteristic of (exclusive to) each of three of the five major substrate and water velocity types in the Springs.

(c) The fauna of Waikoropupu Springs (47 species) and of five other N.Z. cold springs is described and includes phreatic forms, a possible glacial relict and cold stenotherms. The most abundant animals in the N.Z. springs are Amphipoda; Decapoda; larvae of Plecoptera, Diptera and Trichoptera; and Mollusca.

(d) In Waikoropupu Springs, ten common species of invertebrates were found on at least three different substrate and water velocity types but eight species were restricted to (characteristic of) one of three substrate and water velocity types.

(e) When characteristic species of plants and animals are considered, Waikoropupu Springs is seen to consist of five biotopes. Their associated biocoenoses are described and compared with those in cold springs in Denmark and the United States.

3. (a) Notes on the life histories of six species of insects in Waikoropupu Springs are included. Populations of five species of insect (a Plecopteran and four species of Trichoptera) showed seasonal changes in size distribution,

while that of one species of Trichoptera showed no seasonal changes. Some aspects of the biology of the more abundant crustaceans and molluscs are considered.

(b) The life history of Rakiura vernale (Trichoptera: Helicopsychidae) is unusual as this species emerges for only a few weeks in early spring. Its distribution within New Zealand suggests that it is a possible glacial relict in the Springs and its life history may be adapted to colder conditions than now exist there.

4. (a) Four major trophic levels are present in Waikoropupu Springs and are termed Primary Producer, Primary Consumer, Secondary Consumer and Saprophyte. Pyramids of biomass constructed for three sites in the Springs and for the entire study area are broad-based.

(b) Cold springs can be classified according to the extent of the autotrophic component of the trophic system compared to the heterotrophic component. In the springs of largest discharge, energy input is almost entirely derived from photosynthesis within the spring (autotrophy) whilst in the springs of smaller discharge, a considerable proportion of energy input is derived from allochthonous detritus (heterotrophy).

5. (a) A cold spring as an ecological unit should include not only the spring itself but its catchment area and the spring outflow. Waikoropupu Springs and its outflow are compared with four cold springs in other countries.

(b) Waikoropupu Springs is compared in more detail with Silver Springs, Florida (Odum 1957a), a cold spring of comparable discharge. Their biological similarities and differences can largely be explained by reference to similarities and differences in the physical and chemical features outlined under 1 (e) above.

ACKNOWLEDGEMENTS

I am grateful to the Cawthron Institute Trust Board, Nelson for financing this work and to Dr R.H. Thornton and the late Dr F.B. Cousins for providing field equipment and laboratory facilities at the Institute. I am also grateful to Professor G.A. Knox and the Zoology Department, University of Canterbury for the hospitality and facilities offered while in the Department. I thank Dr M.E.U. Taylor, formerly of the Institute, who originally suggested this study, carried out chemical analyses of water from Waikoropupu Springs and organised the underwater survey of the Springs in its initial stages. Mr and Mrs A. Climpson of Wainui Bay kindly provided accommodation during the field work.

I thank the Botany Department, Auckland University (loan of coloured filters); Messrs L.J. Brown, L.O. Kermode and M.R. Johnston of the N.Z. Geological Survey; Miss H.M. Campbell (owner of Waikoropupu Springs); Dr M.D. Cooke (bacteriological analyses); Mr N. Cozens (surveying of the Springs); Entomology Division, D.S.I.R., Nelson (provision of constant temperature facilities and developing film negatives); Golden Bay Enterprises Ltd (loan of a dinghy); Mr L.T. Hunter, Patons Rock (sunshine records); Lands and Survey Department, Nelson (drafting of maps in Part 1); Ministry of Agriculture and Fisheries, Christchurch (loan of current meter); Nelson Speleological Group (loan of rubber dinghy); Nelson Underwater Club Inc.; Photographic Unit, Department of Zoology, University of Canterbury (printing the black and white plates); Mr A.G. Richards, Golden Bay Electric Power Board (temperature and rainfall data, reading of staff gauge).

I thank the following for assistance with identification of plant specimens: K.W. Allison (Bryophyta); Botany Division, D.S.I.R.; E.A. Flint (Algae); E.A. Hodgson (*Neesioscyphus phoenicorhizus*) and R. Mason (aquatic Angiospermae) and of invertebrate specimens: F.R. Allison (Tricladida); R.O. Brinkhurst (Annelida); F. Climo (Mollusca); T.K. Crosby (Diptera); J.S. Dugdale (Diptera, Lepidoptera); A.C. Eyles (Hemiptera); R.R. Forster (Arachnida); D.J. Forsyth (Diptera); D.E. Hurley (Crustacea); P.M. Johns (Diptera); M. Lewis (Crustacea); A.G. McFarlane (Trichoptera); I.D. McLellan (Plecoptera); G.W. Ramsay (Acarina); J.C. Watt (Coleoptera); M.J. Winterbourn (Ephemeroptera) and W.M. Wouts (Nematoda).

I particularly thank Dr M.E.U. Taylor for reading the manuscript of Part 1; Dr E.A. Flint and Miss R. Mason, Botany Division, D.S.I.R. for reading the manuscript of Part 2; Mr A.G. McFarlane for his encouragement with the studies of the caddisflies and all those who helped with the typing of the thesis. My husband, Geoff Wells, assisted me with great skill both on field trips and in the preparation of the thesis figures and plates.

Finally, I would like to thank my supervisors, Drs Vida M. Stout and M. J. Winterbourn of the Zoology Department, University of Canterbury who were a constant help during the study and in the preparation of the thesis.

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LIST OF APPENDICES

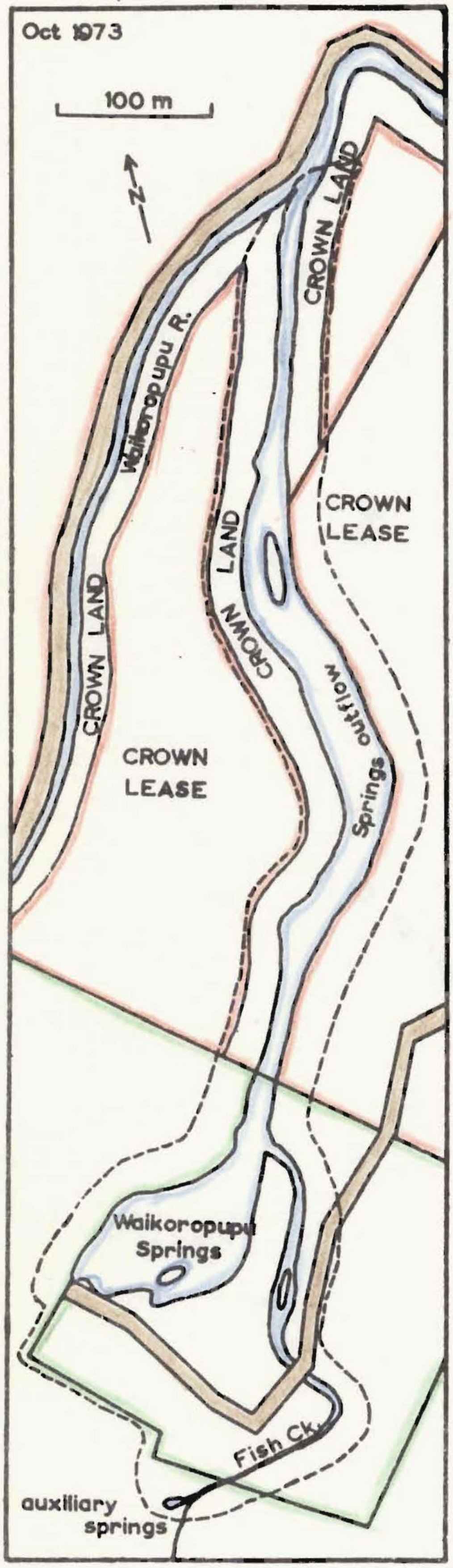

FIG. A.1: Sketch map of Waikoropupu Springs and surrounding area to show Project Aqua site and land ownership. Broken line indicates proposed boundary of Project Aqua site, and solid lines, according to their colour, indicate boundaries: blue for water, red for Crown Land and Crown Lease, green for privately-owned land and brown for legal roads. (Based on Lands and Survey records).

APPENDIX 1: Revised information on Project Aqua site

Name of proposed site: Waikoropupu Springs
Situation: Part Sec. 44 Takaka District Block V Waitapu S.D. Takaka, Nelson Province, New Zealand.
Latitude: 40° 51' S
Longitude: 172° 47' E
Altitude: About 14 m
Area: 0.57 ha (Waikoropupu Springs downstream to the confluence of the Springs outflow and Fish Creek). The Project Aqua site as originally proposed should be extended to include the spring sources of Fish Creek (Gully), Fish Creek itself, Waikoropupu Springs and the Springs outflow as far downstream as its confluence with the Waikoropupu River (NZMS 1/S8 Takaka and accompanying map).
Max. depth: 6.9 m (constant)
Origin: From Arthur Marble. Source probably Takaka River.
Trophic status: Not applicable.
Special scientific interest: Has one of the highest discharge rates of any cold spring in the world (11 m^3/s). The water is of constant temperature (11.7°C) with a chemical composition unlike surface water in the area. An abundant and unique flora and fauna is present on substrates of bedrock, boulders and gravel.
Degree of scientific research: Ecological survey over three years (1970-72).

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Conservation status: None as yet. Spring sources of Fish Creek, Fish Creek itself and Waikoropupu Springs are privately owned. West bank of Springs outflow is Crown Land but east bank is Crown Lease. Original podocarp-hardwood forest removed from around Waikoropupu Springs prior to about 1900; now, scrub and pasture. Fish Creek and the east bank of the Springs outflow have retained a dense forest cover but the west bank of the Springs outflow is periodically burnt, and grazed by cattle, preventing regeneration of native plants.
National recognition: Under consideration.
Present usage: Recreation on a limited scale (tourism and SCUBA diving). Cattle graze emergent vegetation round shoreline.
Threats from possible developments: Scheduled public road (Proclamation 1601).

Frances B. Michaelis
8 October 1973

Maps of Waikoropupu Springs and the surrounding area are deposited with the Department of Lands and Survey, Nelson.

APPENDIX 2: Levels of dissolved oxygen in water from the "principal" vent of the Main Spring and the Dancing Sands, Waikoropupu Springs, on fifteen occasions between 26 Jan 1970 and 26 Sep 1971. Oxygen levels in some duplicate samples are given. A dash denotes data not available.

Date	Dissolved oxygen (g/m^3) Main Spring		Dancing Sands		Gauge height (feet)
26 Jan 1970	6.9	6.8	6.0	6.1	-
27 Jul 1970	6.4	6.5	-	-	-
3 Oct 1970	6.6	6.7	-	-	5.84
8 Nov 1970	6.6	-	-	-	-
6 Dec 1970	6.8	-	6.4	6.6	5.55
10 Jan 1971	6.5	6.6	6.7	6.7	5.62
7 Feb 1971	6.9	-	7.1	6.6	5.40
7 Mar 1971	6.6	-	6.6	-	5.58
4 Apr 1971	6.8	-	6.6	-	5.40
2 May 1971	6.7	-	7.0	7.0	5.63
30 May 1971	6.4	6.5	7.0	-	5.66
27 Jun 1971	6.5	-	6.9	-	5.68
25 Jul 1971	7.0	-	6.8	-	5.59
29 Aug 1971	6.6	-	6.8	-	5.66
26 Sep 1971	6.9	-	6.9	-	5.64

APPENDIX 3: Chemical analyses, made by Dr. M.E.U. Taylor, of water from the "principal" vent of the Main Spring and from the Dancing Sands, Waikoropupu Springs on six occasions between 26 Jan 1970 and 10 Jun 1971. Full analyses were made on the dates indicated and partial analyses, mainly for the major anions and cations, on the remaining dates. The results of partial analyses are not included in Table 1.6, except for the boron analysis. A dash denotes data not available.

a. Main Spring
b. Dancing Sands

a. Main Spring

	Full analyses			Partial analyses		
Date	26 Jan 1970	10 Jan 1971	2 May 1971	27 Jul 1970	8 Mar 1971	10 Jun 1971
pH	7.6	7.4	7.4	-	-	-
Odour	none	none	none	none	none	none
Taste	mineral	mineral	mineral	mineral	mineral	mineral
Colour(A.P.H.A.)	clear	clear	clear	clear	clear	clear
Turbidity (Silica scale)	none	none	none	none	none	none
Specific conductance 25°C (μS/cm)	580	610	759	-	-	-
		(g/m^3)			(g/m^3)	
Acidity, phenolphthalein	7.6	13.0	11.1	-	-	-
Total alkalinity	165	167	157	-	-	-
Total dissolved solids 180°C	354	394	-	-	-	-
Total fixed solids 500°C	326	372	-	-	-	-
Free CO_2	6.7	5.8	4.9	-	-	-
NO_3 - N	0.33	0.29	0.30	-	0.34	-
NO_2 - N	-	0.001	-	-	-	-
NH_4 - N	0.069	0.050	0.004	-	-	-
Total oxidisable N	0.03	0.10	0.09	-	-	-
'Available' P	0.001	0.001	-	0.005	0.009	-
Cl	90	100	115	120	110	121
SO_4 - S	-	59	54	-	-	-
SiO_2 - Si	2.2	2.5	2.4	2.4	-	-
Ca	60	60	72	64	67	70
Mg	6.8	9.4	9.4	10.3	9.2	9.2
Na	50	72	67	-	62	74
K	5.5	5.3	5.4	-	5.6	6.2
Fe	-	-	0.02	-	-	-
B	-	-	-	0.5	-	-
Gauge height (feet)	-	5.62	5.63	-	5.58	5.94

APPENDIX 3 (cont'd.)

b. Dancing Sands

	Full analyses			Partial analyses	
Date	26 Jan 1970	10 Jan 1971	2 May 1971	27 Jul 1970	8 Mar 1971
pH	7.7	7.4	7.4	-	-
Odour	none	none	none	none	none
Taste	mineral	mineral	mineral	mineral	mineral
Colour (A.P.H.A.)	clear	clear	clear	clear	clear
Turbidity (Silica scale)	none	none	none	none	none
Specific conductance 25°C (μS/cm)	514	494	592	-	-
	(g/m^3)			(g/m^3)	
Acidity, phenolphthalein	6.0	8.4	10.0	-	-
Total alkalinity	158	147	155	-	-
Total dissolved solids 180°C	298	316	-	-	-
Total fixed solids 500°C	285	274	-	-	-
Free CO_2	5.3	3.7	4.4	-	-
NO_3 - N	0.33	0.34	0.28	-	-
NO_2 -N	-	<0.001	-	-	-
NH_4 -N	0.06	0.02	<0.001	-	-
Total oxidisable N	0.03	0.10	0.07	-	-
'Available' P	<0.005	<0.001	-	-	-
Cl	56	68	80	70	46
SO_4 -S	-	36	51	-	-
SiO_2 -Si	2.2	2.5	2.3	-	-
Ca	57	52	64	-	60
Mg	6.0	7.0	7.8	-	6.0
Na	39	52	54	-	35
K	4.7	3.7	4.4	-	3.9
Fe	-	nil	0.02	-	-
Gauge height (feet)	-	5.62	5.63	-	5.58

APPENDIX 4: Plate counts of bacteria, made by Dr. M. D. Cooke, from water from the "principal" vent and plants at sites 1 and 7 (<u>Cratoneuropsis relaxa</u> and <u>Nasturtium microphyllum</u> respectively) in Waikoropupu Springs at four-weekly intervals from 6 Dec 1970 to 24 Oct 1971. A dash denotes data not available.

Sampling date	Bacterial plate count: Water (bacterial colonies/ml)	Plants (bacterial colonies/gm wet wt of plant) x 10^4: Site 1	Site 7
6 Dec 1970	140	34	10
10 Jan 1971	160	36	8
	-	-	-
7 Feb 1971	1	12	8
	22	23	10
7 Mar 1971	2371	390	5900
	3490	1100	7800
4 Apr 1971	23000	1	4
	11000	15	8
2 May 1971	35	270	200
	36	13	58
30 May 1971	71	10	160
	186	370	190
27 Jun 1971	38	13	200
	256	8	44
25 Jul 1971	3	9	6
	14	3	4
29 Aug 1971	730	37	71
	5000	6	120
26 Sep 1971	14	67	490
	57	8	420
24 Oct 1971	9	8	4
	6	2	7
MEAN VALUE	7266	118	785

Dry weight of plant as a percentage of wet weight was taken as 7% for moss (18 determinations) and 5% for watercress (17 determinations).

Note: Results of two plate counts of bacteria on <u>Myriophyllum elatinoides</u> at site 6 are recorded in Appendix 14.

APPENDIX 5: Dates of collection, by sweep netting, or observation of adults of aquatic insects whose larvae were found in Waikoropupu Springs (Jan 1970 - Oct 1972). Collections were made for identification purposes, and not to determine the flight period of the insect.

Odonata
Xanthocnemis zealandica

4. xii. 70, 5. xii. 70, 6. xii. 70, 18. xii. 70, 14. i. 71, 6. ii. 71, 1. i. 72, 14. i. 72, 15. i. 72, 19. ii. 72.

Ephemeroptera
Deleatidium myzobranchia

8. xi. 70, 4. xii. 70, 5. xii. 70, 6. xii. 70, 11. i. 71, i. v. 71, 15. v. 71, 29. v. 71, 24. vii. 71, 29. viii. 71.

Zephlebia scita

6. ii. 71, 29. v. 71, 25. x. 71, 4. i. 72, 15. i. 72, 19. ii. 72.

Plecoptera
Megaleptoperla diminuta

1. v. 71.

Trichoptera
Conuxia gunni

16. iv. 70, 5. xii. 70.

Helicopsyche poutini

16. iv. 70, 5. xii. 70.

Oxyethira n.sp.

16. iv. 70, 5. xii. 70, 30. v. 71.

Polyplectropus puerilis

5. xii. 70, 26. ix. 71.

Psilochorema tautoru

26. ix. 71.

Rakiura vernale

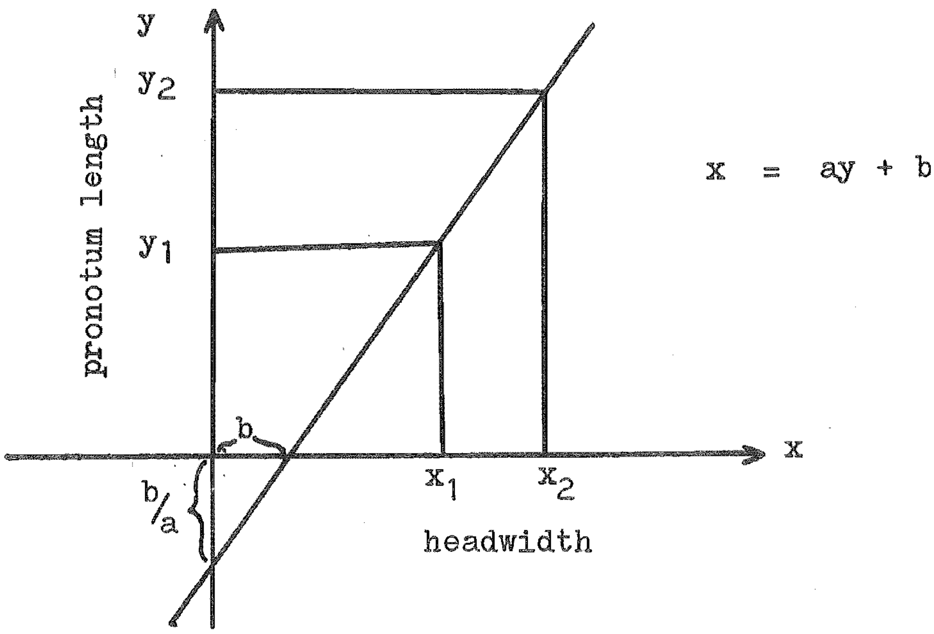
see Part 4, also 1. x. 72.

Zelolessica cheira

8. xi. 70, 5. xii. 70, 18. xii. 70, 9. i. 71, 26. ix. 71, 25. x. 71, 4. i. 72, 19. ii. 72.

APPENDIX 6: Quotient at ecdysis of _Megaleptoperla diminuta_.

(a) Relationship between quotient at ecdysis (headwidth) and quotient at ecdysis (pronotum) for _M. diminuta_.



If an insect has headwidth x_1 and pronotum length y_1 prior to ecdysis and headwidth x_2 and pronotum length y_2 after ecdysis, then, according to Brooks' Rule (Brooks 1886), x_2/x_1 is a constant, k_x, the quotient at ecdysis (headwidth). If the relationship between headwidth and pronotum length of the insect is linear and can be expressed as

$x = ay + b$ where x = headwidth and y = pronotum length

$$\text{then } k_x = \frac{x_2}{x_1} = \frac{ay_2 + b}{ay_1 + b} = \frac{y_2 + b/a}{y_1 + b/a}$$

for _Megaleptoperla diminuta_,

$$x = 1.35 + 0.29 \text{ mm}$$

$$(r = 0.93,\ 167 \text{ df},\ P < 0.01)$$

and the y intercept, $b/a = 0.21$ mm

$$\text{Then } k_x = \frac{y_2 + 0.21}{y_1 + 0.21}$$

APPENDIX 6 (contd.)

(b) Quotient at ecdysis (pronotum) and quotient at ecdysis (headwidth), and duration of instar for individual specimens of M. diminuta reared at 12°C under winter (L/D:8/16) or summer (L/D:16/8) daylength. Quotient at ecdysis (headwidth) was calculated using the formula given in Appendix 6a. A dash denotes data not available.

Daylength (L/D) (hours)	Length of pronotum (mm) before ecdysis (y_1)	Length of pronotum (mm) after ecdysis (y_2)	Pronotum after ecdysis/ pronotum before ecdysis (k_y)	Headwidth after ecdysis/ headwidth before ecdysis (k_x)	Duration of instar in the laboratory (days)
8/16	0.82	0.90	1.10	1.08	7+
16/8	0.85	0.93	1.10	1.08	44-47
8/16	0.70	0.78	1.12	1.09	36+
16/8	0.69	0.78	1.13	1.10	21-25
8/16	1.10	1.26	1.14	1.11	29+
8/16	1.05	1.20	1.15	1.12	30+
8/16	0.52	0.62	1.18	1.14	-
16/8	-	-	-	-	26-30
16/8	0.98	-	-	-	27-35
16/8	0.70	-	-	-	30-32
16/8	0.71	-	-	-	31-35
16/8	0.67	-	-	-	31-36
16/8	-	-	-	-	37-53
8/16	-	0.50	-	-	45-50
8/16	0.70	-	-	-	46-49
16/8	0.66	-	-	-	52-56
16/8	0.78	-	-	-	84-100
		MEAN	1.13	1.10	

APPENDIX 7: Sightings of birds at Waikoropupu Springs. The sightings are from a possible 49 days spent at the Springs (generally from 1000 to 1630 hours) between Jan 1970 and Apr 1972. f = feeding, s = sighted but not feeding, o = flying overhead.

Anas superciliosa - grey duck

1 adult - 8.xi.70 f, 9.x.71 s, 6 adults - 10.i.71 f.

pair plus four young breeding on the island between Main Spring and Dancing Sands - 27.xi.71 f.

Ardea novaehollandiae - white faced heron

3.v.70 s, 8.xi.70 s, 3.iv.71 s, 1.v.71 f, 2.v.71 f, 26.vi.71 s.

Gallirallus australis - weka

18.ix.70 f, 3.x.70 f, 4.xii.70 s, 5.xii.70 s, 6.ii.71 s, 25.ix.71 f, 26.ix.71 s, 9.x.71 s, 19.ii.72 f.

Halcyon sancta - kingfisher

16.iv.72 s.

Phalacrocorax melanoleucos - little shag

16.iv.70 s, 4.v.70 f, 18.ix.70 s, 5.x.70 f, 8.xi. 70 o, 5.xii.70 s, 15.v.71 o, 29.v.71 o, 10.vi.71 f, 26.vi.71 o, 24.vii.71 o, 29.viii.71 o, 9.x.71 s, 25.x.71 o.

Two shags - 11.i.71 s, 6.ii.71 o, 25.ix.71 o, 26.ix.71 s, 16.iv.72 o.

Porphyrio porphyrio - pukeko

8.xi.70 f, 4.xii.70 f.

Rhipidura fuliginosa - fantail

Usually two to six birds - 4.vii.70 f, 5.vii.70 f, 12.vii.70 f, 25.vii.70 f, 3.x.70 f, 5.x.70 f, 29.x.70 s, 8.xi.70 f, 29.v.71 f, 10.vi.71 f, 26.vi.71 f, 24.vii.71 f, 9.x.71 f, 25.x.71 f.

APPENDIX 8: Estimation of numbers of *Potamopyrgus antipodarum*.

At sites other than 1, 4 and 7, numbers of *P. antipodarum* were generally low enough to be counted. At sites 1, 4 and 7, the species was too numerous for counting to be practical, so the mean dry weight of *P. antipodarum* in samples taken over a 12-monthly period was determined as 161 g dry wt. (incl. shell) at site 1, 415 g dry wt. (incl. shell) at site 4 and 272 g dry wt. (incl. shell) at site 7.

Factors to convert dry weight of snails to number of snails were calculated by weighing 10 samples each of 50 snails from each site. Conversion factors are given, together with the 95% confidence interval, as:

1 g dry wt. of *P. antipodarum* (incl. shell) contains

260 $\pm$ 72 individuals (at site 1)

425 $\pm$ 103 individuals (at site 4)

110 $\pm$ 32 individuals (at site 7)

Therefore, at site 1, 161 g dry wt. of *P. antipodarum* contains about 42,000 $\pm$ 12,000 individuals; at site 4, 415 g dry wt. of *P. antipodarum* contains about 176,000 $\pm$ 43,000 individuals; and at site 7, 272 g dry wt. of *P. antipodarum* contains about 30,000 $\pm$ 9,000 individuals.

APPENDIX 9 : Numbers of animals collected per sample at nine sites in Waikoropupu Springs on the sampling dates indicated. Animals were counted, but not collected, at a tenth site. Number of results for each sampling date indicates number of samples taken.

a.	Site 1,	b.	Site 2,	c.	Site 4,	d.	Site 5,
e.	Site 6,	f.	Site 7,	g.	Site 8,	h.	Site 9,
i.	Site 10,	j.	Unstable sand and gravel.				

-	denotes no individuals of that species collected in sample.
N.D	No Data. Individuals, if present in a sample, were either inadequately preserved, lost or deliberately discarded at sorting stage because of insufficient time to sort samples (eg. Site 7, 24 Oct 1971 to 19 Feb 1972 incl.)
n.c.	not counted because numbers were large.
e.	estimated

9a. Site 1

Sampling date	1970 Dec 6	1971 Jan 10	Feb 7	Mar 7	Apr 4	May 2	May 30	June 27	Jul 25	Aug 29	Sep 26	Oct 24	Nov 28	Jan 4	Feb 19	7 Feb 1971 – 4 Jan 1972 Total No.	No/m^2	Abundance index
Standard area sampled (cm^2)	256	240	252	390	385	254	249	356	455	422	266	204	126	318	131	3677		
Species	(no/sample)								(no/sample)									
Temnocephala novaezelandiae	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	1	3	1
Cura pinguis	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	2	5	1
Paracalliope karitane	15	158	17	24	63	68	66	44	27	77	82	10	63	92	8	633	1721	4
Paraleptamphopus sp.	–	8	–	10	–	6	3	–	–	1	26	–	7	–	1	53	144	3
Paratya curvirostris	–	–	–	3	–	1	1	2	–	–	–	–	–	2	–	9	24	2
Paranephrops planifrons	1	4	–	4	–	4	–	1	1	–	–	1	2	2	1	15	44	2
Deleatidium myzobranchia	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	3	1
Megaleptoperla diminuta	3	–	1	1	1	3	1	2	3	–	–	5	3	1	–	21	57	2
Hydora sp.	–	–	–	–	–	–	–	–	1	–	–	–	1	1	1	3	8	1
Ephydridae	–	–	–	1	–	–	2	–	–	–	–	–	–	–	–	3	8	1
Stratiomyidae	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	0	–	–
Limnophora sp.	–	–	1	–	1	–	–	–	–	–	1	–	–	–	–	3	8	1
Limonia sp.	–	–	–	–	–	–	–	–	–	1	–	–	1	–	–	2	5	1
Chironomus zealandicus	–	–	–	–	–	–	–	–	6	–	–	–	–	–	–	6	16	2
Orthocladiinae	–	5	17	29	–	1	1	–	1	22	12	10	6	10	–	109	296	3
Conuxia gunni	22	18	14	–	6	6	23	28	18	156	24	49	91	134	–	549	1493	4
Hydrobiosis parumbripennis	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	3	1
Polyplectropus puerilis	7	1	–	1	1	–	5	3	6	7	2	4	2	8	4	39	106	3
Psilochorema tautoru	1	–	2	3	7	5	8	5	4	12	1	6	7	21	2	81	220	3
Rakiura vernale	–	–	–	–	–	–	2	2	–	–	–	–	–	–	–	4	11	2
Zelolessica cheira	23	8	1	1	–	10	10	34	14	144	44	51	164	53	–	526	1431	4
Potamopyrgus antipodarum	N.D	N.D	N.D.	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	c.40,000	5

9b. Site 2

Sampling date	1970 Oct 5	1971 Apr 3	Sep 26	TOTAL	No/m^2	Abundance index
Area sampled (cm^2)	154	990	470	1614		
	(no/sample)					
Paracalliope karitane	9	5	6	20	123	3
Paraleptamphopus n.sp	8	-	4	12	74	2
Paratya curvirostris	1	-	-	1	6	1
Paranephrops planifrons	-	1	-	1	6	1
Deleatidium myzobranchia	1	-	-	1	6	1
Psilochorema tautoru	-	1	2	3	19	2
Lymnaea columella	-	1	-	1	6	1
Potamopyrgus antipodarum	155	79	93	327	2026	4

9 c. Site 4

Sampling date	1970 Nov 9	Dec 6	1971 Jan 10	Feb 7	Mar 7	Apr 4	May 2	May 30	Jun 27	Jul 25	Aug 29	Sep 26	Oct 24	Nov 28	1972 Jan 4	Feb 19	7 Feb 1971 - 4 Jan 1972 Total no.	No/m^2	Abundance index
Standard area sampled (cm^2)	234	433	250	520	318	570	134	154	178	253	343	296	351	199	141	147	3457		
Species								(no/sample)											
Temnocephala novaezelandiae	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	3	1
Dugesia n.sp	2	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	3	1
Lumbriculus variegatus	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	3	9	1
Paracalliope karitane	N.D	1	307	5	92	214	105	119	105	14	613	38	96	137	214	57	1752	5068	4
Paraleptamphopus sp.	-	-	-	-	-	-	6	13	52	-	-	26	27	13	-	1	137	396	3
Paranephrops planifrons	1	-	1	-	1	2	3	1	1	-	1	-	-	3	-	1	12	35	2
Paratya curvirostris	-	-	-	-	-	1	-	-	-	-	2	-	-	1	-	-	4	12	2
Deleatidium myzobranchia	-	1	-	-	1	1	3	1	-	-	-	5	3	-	1	-	15	43	2
Megaleptoperla diminuta	-	-	-	-	1	2	-	-	-	-	2	1	1	2	-	3	9	26	2
Hydora sp.	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	-	-
Ephydridae	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	3	1
Stratiomyidae	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-
Chironomus zealandicus	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	4	12	2
Orthocladiinae	-	13	-	6	-	4	-	3	-	-	-	8	35	3	2	-	61	176	3
Conuxia gunni	22	18	13	9	-	2	5	1	15	4	26	27	44	36	55	2	224	648	3
Helicopsyche poutini	-	-	-	-	-	-	-	-	2	-	-	2	1	3	-	-	8	23	2
Hudsonema amabilis	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-	2	6	1
Hydrobiosis parumbripennis	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	3	1
Polyplectropus puerilis	6	-	1	-	1	2	-	6	3	1	5	9	2	8	2	-	39	113	3
Psilochorema tautoru	3	3	1	4	2	5	3	3	6	2	-	8	7	22	2	2	64	185	3
Rakiura vernale	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	3	1
Zelolessica cheira	55	16	-	-	-	2	3	3	5	6	9	56	69	10	2	3	165	477	3
Lymnaea columella	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	3	1
Potamopyrgus antipodarum	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	c.180,000	6

9 d. Site 5

Sampling date	1971 Mar 6	Oct 25	1972 Feb 19	TOTAL	No/m^2	Abundance index
Area sampled (cm^2)	900	107	900	1907		
	(no/sample)					
Haplotaxidae	-	3	1	4	21	2
Paracalliope karitane	184	35	203	422	2213	4
Paraleptamphophus sp.	1	2	-	3	16	2
Paratya curvirostris	-	-	3	3	16	2
Paranephrops planifrons	1	-	1	2	10	2
Deleatidium myzobranchia	8	-	6	14	73	2
Megaleptoperla diminuta	1	-	2	3	16	2
Orthocladiinae	4	3	5	12	63	2
Helicopsyche poutini	-	-	1	1	5	1
Polyplectropus puerilis	1	2	2	5	26	2
Psilochorema tautoru	4	3	2	9	47	2
Rakiura vernale	9	2	8	19	99	2
Zelolessica cheira	3	4	-	7	37	2
Potamopyrgus antipodarum	e.2500	184	e.2000	e.4684	e.25,000	5

9 e. Site 6

	1971 May 2	May 2	Oct 24	Jan 16	TOTAL	No/m^2	Abundance index
Area sampled (cm^2)	900	900	900	900	3600		
	(no/sample)						
Haplotaxidae	-	-	-	4	4	11	2
Paracalliope karitane	143	153	82	213	591	1641	4
Paraleptamphophus n.sp.	24	2	-	2	28	78	2
Paratya curvirostris	3	-	5	2	10	28	2
Paranephrops planifrons	1	2	3	8	14	39	2
Chironomus zealandicus	1	-	-	1	2	6	1
Orthocladiinae	1	1	18	5	25	69	2
Conuxia gunni	-	-	3	-	3	8	1
Polyplectropus puerilis	-	1	5	3	9	25	2
Psilochorema tautoru	-	1	11	2	13	36	2
Potamopyrgus antipodarum	e.250	192	108	341	891	2475	4

9 f. Site 7. All samples were 400 cm^2 so that the total area sampled between 9 Nov 1970 and 26 Sep 1971 was 1.36 m^2

1970								1971											
Oct 4				Nov 9		Dec 6		Jan 10			Feb 7			Mar 7			Apr 4		
								(no/sample)											
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	10	43	5	-	1	-	3	-	1	9	6	1	50	8	15	101	188	308	23
-	15	1	-	-	-	2	1	-	-	16	1	-	5	1	-	-	1	1	6
-	-	-	-	-	-	63	69	-	-	-	-	-	-	-	-	-	-	-	159
N.D	N.D	N.D	N.D	2	-	14	97	17	13	2	6	25	1	1	168	16	-	-	26
N.D	N.D	N.D	N.D	-	-	2	-	4	1	-	1	2	15	17	10	20	-	-	28
10	17	5	5	3	7	-	4	-	-	5	-	1	1	1	-	2	1	-	-
-	1	2	-	2	2	-	1	-	4	-	-	-	-	-	3	3	-	-	1
1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	3	-	1	-	-
-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	4	-	-	-	5
2	1	-	-	1	19	9	3	-	4	-	6	4	2	12	22	17	8	6	9
-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	2	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	1	1	2	-	-	4	1	-	-	-
-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
-	1	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	1	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-
-	-	1	-	1	-	-	2	-	-	-	-	3	1	2	4	-	-	-	3
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
-	-	1	-	N.D	N.D	7	-	-	2	-	1	2	3	5	9	1	5	2	5
n.c	N.D.	n.c		n.c		n.c			n.c			n.c			n.c			n.c	
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

9 f. Site 7. (contd.)

1971																	
May 2			May 30			Jun 27			July 25			Aug 29			Sep 26		
								(no/sample)									
–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–
17	10	8	71	11	60	8	3	12	10	13	10	–	5	5	3	4	3
–	–	–	12	59	4	10	–	–	1	1	–	1	4	–	–	1	1
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	24	–	7	–	1	1	22	4	7	52	3	4	34	–	28	1	40
–	1	–	–	–	1	1	–	–	3	–	1	3	1	–	3	–	1
6	–	1	1	5	1	1	4	1	4	7	2	1	7	1	1	–	–
–	–	–	–	–	–	–	1	–	1	–	1	–	–	–	–	2	2
1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–
–	–	–	1	–	–	–	1	–	1	1	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
–	–	–	–	10	–	–	–	–	–	–	–	–	–	–	–	–	–
5	2	10	1	–	1	4	8	8	3	1	1	1	–	–	3	–	3
–	–	–	1	–	–	–	–	1	–	–	–	–	–	–	–	–	–
–	–	–	–	–	1	1	–	2	–	–	–	–	–	–	–	–	–
2	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	1
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	2	2	–	–	–	–	–	–	1
–	1	2	2	–	1	3	2	–	2	2	–	–	–	–	–	–	–
–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
3	2	3	9	11	1	16	3	2	22	22	8	–	2	3	2	–	1
	n.c			n.c			n.c	N.D.		n.c			n.c			n.c	
–	3	–	3	1	1	–	2	1	2	–	–	–	–	–	–	–	–
–	–	1	–	–	–	–	–	–	–	–	–	12	2	4	1	16	1
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

9 f. Site 7 (contd)

1971											9 Nov 1970 - 26 Sep 1971			
Oct 24			Nov 28			Jan 4			Feb 19		Total No.	No/m^2	Abundance index	Species
				(no/sample)										
											1	0.7	-	*Cura pinguis*
											967	711	3	*Lumbriculus variegatus*
				N.D.							128	93	2	*Herpetocypris pascheri*
											291	214	3	*Tropocyclops prasinus*
											616	453	3	*Paracalliope karitane*
											115	85	2	*Paraleptamphopus* sp.
-	-	-	-	1	3	8	1	-	-	-	68	50	2	*Paratya curvirostris*
-	-	-	-	-	-	-	-	-	1	-	23	17	2	*Paranephrops planifrons*
											8	6	1	*Dolomedes* sp.
				N.D.							5	4	1	*Xanthocnemis zealandica*
											3	2	1	*Deleatidium myzobranchia*
											20	15	2	*Microvelia macgregori*
-	-	-	2	1	3	-	1	-	-	1	173	127	3	*Megaleptoperla diminuta*
											5	4	1	Stratiomyidae
											4	3	1	*Chironomus zealandicus*
											14	10	2	Orthocladiinae
				N.D.							0	-	-	*Helicopsyche poutini*
											2	1	1	*Hydrobiosis parumbripennis*
											0	-	-	*Oxyethira* n. sp.
											7	5	1	*Polyplectropus puerilis*
-	-	-	1	1	-	-	2	-	-	-	31	23	2	*Psilochorema tautoru*
				N.D.							1	0.7	-	*Rakiura vernale*
											2	1	1	*Zelolessica cheira*
N.D	N.D	N.D	28	19	17	2	8	1	N.D	N.D	152	112	3	*Lymnaea columella*
											n.c	e.30,000	5	*Potamopyrgus antipodarum*
				N.D.							14	10	2	*Agriolimax agrestis*
											37	27	2	*Sphaerium novaezelandiae*
1	-	1	1	1	-	-	1	-	-	-	0	-	-	*Anguilla australis schmidtii*

9 g. Site 8

Sampling date	1971 May 30	Oct 26	1972 Jan 16	TOTAL	No/m^2	Abundance index
Area sampled (cm^2)	e.750	900	e.200	1850		
		(no/sample)				
Paracalliope karitane	38	82	5	125	676	3
Polyplectropus puerilis	-	3	-	3	16	2
Potamopyrgus antipodarum	207	194	68	469	2535	4

9 h. Site 9

Sampling date	1970 Dec 6	1971 May 29	Oct 26	1972 Jan 16	TOTAL	No/m^2	Abundance index
Area sampled (cm^2)	e.400	e.250	200	e.200	e.1050		
		(no/sample)					
Paracalliope karitane	21	16	7	12	56	533	3
Psilochorema tautoru	1	-	-	-	1	9	1
Potamopyrgus antipodarum	147	123	87	63	420	4000	4
Anguilla australis schmidtii	-	-	1	-	1	9	1

9 i. Site 10

Sampling date	1971 Mar 11	May 15	Sep 24	Nov 26	TOTAL	No/m^2	Abundance index
Area sampled (cm^2)	216	106	330	101	753		
		(no/sample)					
Dugesia n.sp.	2	19	35	10	66	876	3
Deleatidium myzobranchia	4	23	17	8	52	691	3
Helicopsyche poutini	2	-	3	1	6	80	2
Hydrobiosis parumbripennis	1	2	-	-	3	40	2
Psilochorema tautoru	-	-	1	3	4	52	2
Rakiura vernale	9	20	1	14	44	584	3
Potamopyrgus antipodarum	50	82	15	69	216	2868	4

9 j. Unstable sand and gravel near stand S
(quadrat counts)

Date	1971 Mar 11								
Quadrat area (cm^2)	100	100	100	100	100	100	100	100	100
Potamopyrgus antipodarum	23	107	24	106	106	150	111	27	30

(contd)

					TOTAL	No/m^2	Abundance index
Quadrat area (cm^2)	100	100	100	100	1300		
Potamopyrgus antipodarum	65	65	83	25	922	7092	4

APPENDIX 10: Abundance of common aquatic animals at nine sites in Waikoropupu Springs. Abundance is based on a logarithmic index (see text). Substrate abbreviations are: C.r. - *Cratoneuropsis relaxa*; L. - *Lophocolea*, *Neesioscyphus* and *Cyathophorum*; J.m. - *Juncus microcephalus*; N.m. - *Nasturtium microphyllum*; M.e. - *Myriophyllum elatinoides*; b - boulders.

Site	1	2	4	5	6	7	8	9	10
Substrate	C.r.	C.r.	L.	J.m.	M.e.	N.m.	N.m.	N.m.	b
Depth (m)	0.6	4.3	0.6	0.5	2.5	0	2.5	6.5	0.5
Distance from shore (m)	4	16	15	7	15	2	10	19	8
Number of samples	12	3	12	3	4	34	3	4	4
Species									
Platyhelminthes									
Temnocephala novaezelandiae	1		1						
Cura pinguis	1								
Dugesia n.sp.			1						3
Annelida									
Lumbriculus variegatus			1			3			
Haplotaxidae				2	2				
Crustacea									
Herpetocypris pascheri						2			
Tropocyclops prasinus						3			
Paracalliope karitane	4	3	4	4	4	3	3	3	
Paraleptamphopus n.sp.	3	2	3	2	2	2			
Paratya curvirostris	2	1	2	2	2	2			
Paranephrops planifrons	2	1	2	2	2	2			
Insecta:Odonata									
Xanthocnemis zealandica						1			
:Ephemeroptera									
Deleatidium myzobranchia	1	1	2	2		1			3
:Plecoptera									
Megaleptoperla diminuta	2		2	2		3			
:Coleoptera									
Hydora sp.	1								
:Diptera									
Ephydridae	1		1						
Stratiomyidae	1					1			
Limnophora sp.	1								
Limonia sp.	1								
Chironomus zealandicus	2		2		1	1			
Orthocladiinae	3		3	2	2	2			
:Trichoptera									
Conuxia gunni	4		3		1				
Helicopsyche poutini			2	1					2
Hudsonema amabilis			1						
Hydrobiosis parumbripennis	1		1			1			2
Polyplectropus puerilis	3		3	2	2	1	2		
Psilochorema tautoru	3	2	3	2	2	2		1	2
Rakiura vernale	2		1	2					3
Zelolessica cheira	4		3	2		1			
Mollusca									
Lymnaea columella		1	1			3			
Potamopyrgus antipodarum	5	3	6	5	4	5	4	4	4
Sphaerium novaezelandiae						2			

APPENDIX 11: Dry weights of species of animals, not reported in Appendix 13, from Waikoropupu Springs. Results are expressed as dry weight/individual and are usually based on ten specimens of a given size of each species. Only values greater than 0.05 mg are reported.

	Dry Weight (mg)
Temnocephala novaezelandiae	0.2
Cura pinguis	0.2
Dugesia sp.	0.2
Herpetocypris pascheri	0.1
Paraleptamphopus sp.	0.1
Xanthocnemis zealandica (headwidth 2.3-2.7 mm)	2.4
Deleatidium myzobranchia (middle instar)	2.3
Hydora sp.	0.1
Ephydridae (larva)	0.1
Stratiomyidae (larva)	0.9
Limnophora sp. (larva)	2.0
Limonia sp. (larva)	2.0
Chironomus zealandicus (F instar)	1.6
(F-1 instar)	0.4
Helicopsyche poutini (later instar)	0.7
Hudsonema amabilis (early instar)	0.8
(pupa)	3.0
Hydrobiosis parumbripennis (later instar)	2.4
Rakiura vernale (middle instar)	1.0
Dolomedes sp. (juvenile)	8.7
(mature)	100
Agriolimax agrestis	5.6
Sphaerium novaezelandiae	0.3

APPENDIX 12: Biomass of species of animal collected at three sites in Waikoropupu Springs on the sampling dates indicated. Results are expressed as dry weights (g/m^2). Number of results for each sampling date indicates number of samples taken.

a. Site 1 (moss), b. Site 4 (liverwort), c. Site 7 (watercress).

+	denotes species present with a biomass less than 0.01 g/m^2.
-	denotes no individuals of that species collected in sample.
N.D.	No Data. Individuals, if present in a sample, were either inadequately preserved, lost or deliberately discarded at sorting stage because of insufficient time to sort samples (e.g. Site 7 - 24 Oct 1971 to 19 Feb 1972 incl.)

12 a. Site 1

Sampling date	1970 Dec 6	1971 Jan 10	Feb 7	Mar 7	Apr 4	May 2	May 30	Jun 27	Jul 25	Aug 29	Sep 26	Oct 24	Nov 28	1972 Jan 4	Feb 19
Standard area sampled (cm^2)	256	240	252	390	385	254	249	356	455	422	266	204	126	318	131
Species							(g/m^2)								
Paracalliope karitane	0.14	1.34	0.14	0.11	0.31	0.54	0.62	0.12	0.06	0.28	0.38	0.12	0.03	0.62	0.22
Paratya curvirostris	-	-	-	1.8	-	0.9	0.9	2.6	-	-	-	-	-	2.8	-
Paranephrops planifrons	19.8	40.3	-	16.4	-	5.3	-	28.2	11.2	-	-	60.2	122.2	0.4	4.6
Megaleptoperla diminuta	+	-	0.04	0.03	0.03	0.33	0.05	0.46	0.05	-	-	0.40	0.02	+	-
Orthocladiinae	-	+	0.22	0.23	-	+	+	-	+	0.02	0.07	0.06	0.35	0.04	-
Conuxia gunni	0.23	0.80	0.81	-	0.13	0.12	0.18	0.04	0.20	2.60	0.39	2.08	4.83	3.66	-
Polyplectropus puerilis	0.27	0.08	-	+	+	-	+	+	0.02	0.03	0.02	0.04	0.18	0.48	0.07
Psilochorema tautoru	0.06	-	0.06	0.08	0.20	0.09	0.23	0.21	0.08	0.22	0.05	0.30	0.76	0.82	0.15
Zelolessica cheira	0.61	0.24	0.02	0.02	-	0.16	0.12	0.52	0.13	0.43	0.47	0.93	6.11	1.10	-
Potamopyrgus antipodarum (excl. shell)	20.9	17.5	16.0	9.8	18.1	25.7	20.9	20.7	7.5	16.2	6.3	10.3	63.1	22.3	5.3
Temnocephala novaezelandiae	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Cura pinguis	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-
Paraleptamphopus sp.	-	0.03	-	0.03	-	0.02	0.01	-	-	+	0.10	-	0.06	-	+
Deleatidium myzobranchia	-	-	-	-	-	-	-	-	-	-	-	0.11	-	-	-
Hydora sp.	-	-	-	-	-	-	-	-	+	-	-	-	+	+	+
Stratiomyidae	-	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-
Limnophora sp.	-	-	0.08	-	0.05	-	-	-	-	-	0.08	-	-	-	-
Ephydridae	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-
Limonia sp.	-	-	-	-	-	-	-	-	-	0.05	-	-	0.16	-	-
Chironomus zealandicus	-	-	-	-	-	-	-	-	0.15	-	-	-	-	-	-
Hydrobiosis parumbripennis	-	-	-	-	-	-	-	-	-	-	-	-	-	0.08	-
Kakiura vernale	-	-	-	-	-	-	0.07	0.05	-	-	-	-	-	-	-
Total	42.0	60.3	17.4	28.5	18.8	33.2	23.2	52.9	19.4	19.8	7.9	74.5	198.7	32.3	10.3

12 B. Site 4.

Sampling date	1970 Nov 9	Dec 6	1971 Jan 10	Feb 7	Mar 7	Apr 4	May 2	May 30	June 27	Jul 25	Aug 29	Sep 26	Oct 24	Nov 28	1972 Jan 4	Feb 19
Standard area sampled (cm^2)	234	433	250	520	318	570	134	154	178	253	343	296	351	199	141	147
Species						(g/m^2)										
Paracalliope karitane	N.D.	0.01	3.11	0.05	0.67	0.78	1.13	1.83	1.66	0.13	5.39	0.21	0.79	1.91	4.71	0.94
Paratya curvirostris	-	-	-	-	-	0.4	-	-	-	-	1.3	-	-	1.2	-	-
Paranephrops planifrons	4.3	-	0.3	-	0.2	2.1	47.2	4.0	0.2	-	1.8	-	-	6.5	-	0.5
Megaleptoperla diminuta	0.01	-	-	-	0.04	0.02	-	-	-	-	0.04	0.24	+	0.01	-	0.16
Orthocladiinae	-	0.01	-	0.08	-	0.03	-	0.12	-	-	-	0.04	0.05	0.11	0.06	-
Conuxia gunni	1.14	0.08	0.65	0.16	-	+	0.01	+	0.24	0.06	0.49	0.25	1.14	1.80	3.98	0.17
Polyplectropus puerilis	0.35	-	0.08	-	+	+	-	0.01	0.12	+	0.01	0.05	+	0.51	0.27	-
Psilochorema tautoru	0.13	0.07	0.06	0.08	0.09	0.06	0.11	0.20	0.35	0.11	-	0.30	0.19	1.05	0.20	0.12
Zelolessica cheira	0.31	0.10	-	-	-	+	+	0.02	0.01	0.08	0.12	0.41	0.43	0.19	0.06	0.14
Potamopyrgus antipodarum (exclud. shell)	N.D.	20.7	45.9	30.0	22.9	26.1	70.9	83.8	70.3	48.2	21.7	41.5	31.4	74.9	109.2	25.3
Temnocephala novaezelandiae	0.01	-	-	-	-	0.1	-	-	-	-	-	-	-	-	-	-
Dugesia n.sp.	0.01	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Lumbriculus variegatus	-	-	-	-	-	-	-	-	-	-	-	-	-	0.06	-	-
Paraleptamphopus sp.	-	-	-	-	-	-	0.05	0.08	0.29	-	-	0.09	0.08	0.07	-	+
Deleatidium myzobranchia	-	0.05	-	-	0.07	0.04	0.52	0.15	0.06	-	-	0.39	0.20	-	0.16	-
Hydora sp.	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Stratiomyidae	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Ephydridae	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Chironomus zealandcus	-	-	-	-	-	-	-	-	0.36	-	-	-	-	-	-	-
Helicopsyche poutii	-	-	-	-	-	-	-	-	0.04	-	-	0.05	0.03	0.17	-	-
Hudsonema amabilis	-	-	-	-	-	-	-	0.22	-	-	-	0.03	-	-	-	-
Hydrobiosis parumbipennis	-	-	-	-	0.08	-	-	-	-	-	-	-	-	-	-	-
akiura vernale	-	-	-	-	-	-	-	-	-	-	0.05	-	-	-	-	-
Lymnaea columella	-	-	-	-	-	-	-	-	-	-	-	0.34	-	-	-	-
Total	N.D.	21.0	50.1	30.4	24.1	19.5	119.9	90.4	73.5	48.6	30.9	43.9	34.3	88.5	118.6	27.3

1970								1971											
Oct 4				Nov 9		Dec 6		Jan 10			Feb 7			Mar 7			Apr 4		
									(g/m^2)										
0.10	0.12	0.50	0.06	-	0.01	-	0.03	-	0.01	0.10	0.07	0.01	0.58	0.09	0.17	1.16	2.16	3.54	0.27
N.D.	N.D.	N.D.	N.D.	0.02	-	0.11	0.73	0.13	0.10	0.02	0.05	0.19	+	+	1.26	0.12	-	-	0.20
12.1	20.0	6.0	6.0	2.5	7.7	-	6.2	-	-	6.0	-	0.8	2.7	2.7	-	1.7	0.8	-	-
-	0.1	0.2	-	2.7	0.3	-	0.3	-	1.2	-	-	-	-	-	23.1	23.1	-	-	0.9
0.33	0.28	-	-	0.04	3.64	0.16	0.05	-	0.06	-	0.22	0.14	0.05	0.77	1.80	1.19	0.35	0.46	0.84
-	-	0.01	-	0.01	-	-	0.07	-	-	-	-	0.11	0.06	0.07	0.13	-	-	-	0.03
14.9	N.D.	17.2	27.7	18.1	15.7	24.3	19.8	15.7	40.1	21.6	28.3	28.5	23.9	42.8	9.5	43.6	33.7	47.9	20.6
-	-	0.09	-	N.D.	N.D.	0.69	-	-	0.42	-	0.05	0.12	0.12	0.36	1.16	0.02	0.24	0.12	0.24
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	0.05	+	-	-	-	+	+	-	-	0.05	+	-	0.02	+	-	-	+	+	0.02
-	-	+	-	-	+	+	+	-	+	-	+	-	-	-	+	-	-	-	+
N.D.	N.D.	N.D.	N.D.	-	-	+	-	0.01	+	-	+	+	0.04	0.04	0.03	0.05	-	-	0.07
-	-	-	-	-	-	-	-	-	-	-	0.06	-	-	-	-	-	-	-	-
-	-	-	-	0.06	-	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	+
-	0.02	-	-	-	-	-	-	-	-	-	0.02	-	-	-	0.04	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	+	+	0.02	-	-	0.04	0.02	-	-	-
-	0.02	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.06	-	0.06
-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	0.08	-	-	0.08	-	-	-	-	-	-	0.08	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	0.02	-	-	-	-	-	-	0.02	-	-	-	-	-	-	-	-
0.22	-	-	-	-	0.22	-	-	-	-	-	-	-	-	-	2.98	-	0.22	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.14	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50.3	-	-	15.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

1971

May 2			May 30			June 27			July 25			Aug 29			Sep 26		
							(g/m^2)										
0.20	0.12	0.09	0.82	0.13	0.69	0.09	0.04	0.14	0.12	0.15	0.12	-	0.06	0.06	0.03	0.05	0.03
-	0.18	-	0.05	-	0.08	0.08	0.17	0.03	0.05	0.39	0.02	0.03	0.26	-	0.21	+	0.30
5.0	-	2.7	0.8	6.0	0.8	2.7	8.[illegible]	0.8	6.2	9.6	1.7	0.8	13.2	0.8	0.8	-	-
-	-	-	-	-	-	-	20.4	-	2.4	-	0.3	-	-	-	-	0.6	0.6
0.94	0.33	1.16	0.04	-	0.04	0.18	0.55	0.27	0.13	0.04	0.04	0.04	-	-	0.57	-	0.37
-	+	0.07	0.06	-	0.01	0.07	0.07	-	0.01	0.06	-	-	-	-	-	-	-
38.3	39.2	20.6	48.7	28.5	107.1	50.9	17.2	N.D.	45.9	51.8	34.2	36.9	51.8	10.9	11.1	25.8	24.1
0.17	0.08	0.08	0.33	0.33	0.15	0.57	0.30	0.15	0.99	1.08	0.36	-	0.08	0.18	0.06	-	0.09
-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
-	-	-	0.04	0.18	0.01	0.03	-	-	+	+	-	+	0.01	-	-	+	+
-	-	-	-	+	-	+	+	+	-	-	+	-	+	-	-	+	+
-	+	-	-	-	+	+	-	-	+	-	+	+	+	-	+	-	+
-	-	-	0.06	-	-	-	0.06	-	0.06	0.06	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	0.06	-	-	-	-	-	-	-	-	-
-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	0.02	-	-	-	-	0.02	-	-	-	-	-	-	-	-	-
-	-	-	-	-	0.04	0.04	-	0.08	-	-	-	-	-	-	-	-	-
0.02	-	-	-	0.02	0.02	-	-	-	-	-	-	-	-	-	-	-	+
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	0.03	0.02	-	-	-	-	-	-	0.03
-	-	-	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.44	-	-
-	0.45	-	0.42	0.14	0.14	-	0.28	0.14	0.28	-	-	-	-	-	-	-	-
-	-	-	-	-	+	-	-	-	-	-	-	0.09	0.02	0.03	+	0.12	+
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

12c. Site 7 (contd.)

1971						1972					Sampling date
Oct 24			Nov 28			Jan 4			Feb 19		
(g/m^2)											species
N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	*Lumbriculus variegatus*
N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	*Paracalliope karitane*
-	-	-	-	0.8	4.4	12.2	2.7	-	-	-	*Paratya curvirostris*
-	-	-	-	-	-	-	-	-	2.4	-	*Paranephrops planifrons*
-	-	-	0.29	+	0.01	-	0.04	-	-	0.04	*Megaleptoperla diminuta*
-	-	-	0.01	0.01	-	-	0.07	-	-	-	*Psilochorema tautoru*
N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	*Potamopyrgus antipodarum* (excl. shell)
N.D.	N.D.	N.D.	0.63	0.29	0.28	0.08	0.27	0.06	N.D.	N.D.	*Lymnaea columella* (excl. shell)
											Cura pinguis
											Herpetocypris pascheri
											Tropocyclops prasinus
											Paraleptamphopus sp.
											Xanthocnemis zealandica
				N.D.							*Deleatidium myzobranchia*
											Microvelia macgregori
											Stratiomyidae
											Chironomus zealandicus
											Orthocladiinae
											Helicopsyche poutini
											Hydrobiosis parumbripennis
											Oxyethira n.sp.
											Polyplectropus puerilis
											Rakiura vernale
											Zelolessica cheira
											Dolomedes ?n.sp
											Agriolimax agrestis
											Sphaerium noveazelandiae
77.5	-	17.3	44.0	36.3	-	-	29.0	-	-	-	*Anguilla australis schmidtii*

APPENDIX 13: Biomass of major species of plants and animals at three sites in Waikoropupu Springs in autumn (4 April) 1971 and spring (28 November) 1971, arranged according to trophic level probably occupied by the species. Only species that contribute more than 1% of the biomass to a given trophic level are considered.
Abbreviations used: C.L. - carapace length, F final, F-1 final but one (penultimate), F-2 final but two, F-3 final but three, H.W. - headwidth, indiv. - individual(s) (of), N.D. - not determined, resp. - respectively, SA - standard area.

a. Site 1 (moss)
b. Site 4 (liverwort)
c. Site 7 (watercress)

Component and basis for calculation	Biomass (dry weight) (g/m^2) autumn 1971	Biomass (dry weight) (g/m^2) spring 1971
a. Site 1 (moss)		
PRODUCERS		
Algae		
Spirogyra sp. Values from single samples on 4 Apr 71, 4.6 g from a SA of 385 cm^2 and 28 Nov 71, 1.2 g from a SA of 126 cm^2.	120	90
Bryophytes		
Cratoneuropsis relaxa and _Fissidens rigidulus_ Mean dry weight value from Table 2.8 and no significant seasonal change in biomass (Fig. 2.6).	1070	1070
PRIMARY CONSUMERS		
Paracalliope karitane Mean dry wt. of 15 samples from Dec 70 - Feb 72 (Appendix 12a). Total SA sampled 4304 cm^2 containing 192 indiv. length 2 mm at 0.05 mg dry wt/indiv; 407 indiv. length 3 mm at 0.16 mg dry wt/indiv; 188 indiv. length 4 mm at 0.30 mg dry wt/indiv; 40 indiv. length 5 mm at 0.52 mg dry wt/indiv.	0.4	0.4
Paratya curvirostris Samples as for _Paracalliope karitane_, containing 8 indiv. C.L. 5.0-6.5 mm at 0.021 g dry wt/indiv; 1 indiv. C.L. 6.6-9.0 mm at 0.067 g dry wt/indiv.	0.6	0.6
Paranephrops planifrons Samples as for _Paracalliope karitane_, containing 9 indiv. of C.L. 3.5-6.0 mm at 0.0073 g dry wt/indiv; 5 indiv. of C.L. 6.1-10.0 mm at 0.061 g dry wt/indiv; 6 indiv. of C.L. 10.1-15.0 mm at 0.51 g dry wt/indiv; 1 indiv. of C.L. 15.1-20.0 mm at 1.23 g dry	20.8	20.8

APPENDIX 13 (cont'd.)

Component and basis for calculation	autumn 1971	spring 1971
wt/indiv; 1 indiv. of C.L. 20 mm at 1.55 g dry wt/indiv.		
Orthocladiinae 4 Apr 71 and 28 Nov 71 values from Appendix 12a i.e. Apr :-, Nov : 6 F instars at 0.73 g dry wt/indiv.	0.1	0.4
<u>Conuxia gunni</u> 4 Apr 71 and 28 Nov 71 values from Appendix 12a i.e. Apr : 6 P at 0.83 mg dry wt/indiv., Nov : 36 F-1 instars at 0.05 mg dry wt/indiv; 30 F instars at 1.25 mg dry wt/indiv; 26 P at 0.83 mg dry wt/indiv.	0.1	4.8
<u>Zelolessica cheira</u> 4 Apr 71 and 28 Nov 71 values from Appendix 12a i.e. Apr :-, Nov : 14 F-1 instars at 0.10 mg dry wt/indiv; 98 F instars at 0.77 mg dry wt/indiv.	<0.1	6.1
<u>Potamopyrgus antipodarum</u> (excluding shell)* Samples as for <u>Paracalliope karitane</u>. Mean dry wt. from Appendix 12a.	18.7	18.7
SECONDARY CONSUMERS		
<u>Psilochorema tautoru</u> 4 Apr 71 and 28 Nov 71 values from Appendix 12a i.e. Apr : 2 F-1 instars at 0.3 mg dry wt/indiv; 5 F instars at 1.4 mg dry wt/indiv. Nov : 5 F instars at 1.4 mg dry wt/indiv; 2 P at 1.4 mg dry wt/indiv.	0.20	0.76
<u>Polyplectropus puerilis</u> 4 Apr 71 and 28 Nov 71 values from Appendix 12a i.e. Apr : - and Nov : 1 F-2 instar at 0.05 mg dry wt/indiv; 1 F-1 instar at 0.27 mg dry wt/indiv; 1 F instar at 1.9 mg dry wt/indiv.	<0.01	0.18
<u>Anguilla dieffenbachii</u> Refer to Appendix 14	0.39	0.39
<u>Salmo trutta</u> Refer to Appendix 14	0.51	0.51
SAPROPHYTES Mean bacterial count 1.2×10^6/g wet wt of moss or 1.7×10^7/g dry wt of moss since dry wt of moss is 7% wet wt (Appendix 4). Mean biomass moss 1070 g dry wt/m^2 so bacterial count 1.8×10^{10}/m^2. Since 10^9 cells <u>Escherischia coli</u> (which are of comparable size and shape to bacteria at the Springs) weigh 0.32 mg (dry wt) (Meynell and Meynell 1970) bacteria in moss are estimated to have a biomass of 5.8 mg/m^2.	0.006	0.00[illegible]

Component and basis for calculation	autumn 1971	spring 1971
b. Site 4 (liverwort)		
PRODUCERS		
Lophocolea spp., Neesioscyphus phoenicorhizus and Cyathophorum bulbosum Mean dry wt. value from Table 2.8 and no significant seasonal change in biomass (Part 2).	570	570
Paracalliope karitane Mean dry wt. of 15 samples, Dec 70 - Feb 72 (Appendix 12b) from total SA sampled 4287 cm containing 73 indiv. length 2 mm at 0.05 mg dry wt/indiv; 785 indiv. length 3 mm at 0.16 mg dry wt/indiv; 899 indiv. length 4 mm at 0.30 mg dry wt/indiv; 362 indiv. length 5 mm at 0.52 mg dry wt/indiv.	1.6	1.6
Paratya curvirostris Mean dry wt. of 16 samples. Nov 70 - Feb 72 (Appendix 12b) from total SA sampled 4521 cm^2 containing 4 indiv. C.L. 5.0-6.5 mm at 0.021 g dry wt/indiv.	0.2	0.2
Paranephrops planifrons Samples as for Paratya curvirostris containing 5 indiv. C.L. 3.5-6.0 mm at 0.0073 g dry wt/indiv; 9 indiv. C.L. 6.1-10.0 mm at 0.061 g dry wt/indiv; 1 indiv. C.L. 10.1-15.0 mm at 0.51 g dry wt/indiv.	4.2	4.2
Orthocladiinae 4 Apr 71 and 28 Nov 71 values from Appendix 12b i.e. Nov: 3 F instars at 0.73 mg dry wt/indiv. Apr: —.	<0.1	0.1
Conuxia gunni 4 Apr 71 and 28 Nov 71 values from Appendix 12b i.e. Apr : -, Nov : 13 P at 0.83 mg dry wt/indiv; 20 F instar at 1.25 mg dry wt/indiv; 3 F-1 instars at 0.05 mg dry wt/indiv.	<0.1	1.8
Zelolessica cheira 4 Apr 71 and 28 Nov 71 values from Appendix 12b i.e. Apr : less than 0.01 g/m^2; Nov : 4 F instars at 0.98 mg dry wt/indiv; 6 F-1 instars at 0.10 mg dry wt/indiv.	<0.1	0.2
Potamopyrgus antipodarum (excluding shell)* Samples as for Paracalliope karitane. Mean dry wt. from Appendix 12b.	48.2	48.2

APPENDIX 13 (cont'd.)

Component and basis for calculation	autumn 1971	spring 1971
SECONDARY CONSUMERS		
Polyplectropus puerilis 4 Apr 71 and 28 Nov 71 values from Appendix 12b i.e. Apr : less than 0.01 g/m^2; Nov : 5 F instars at 1.9 mg dry wt/indiv; 3 F-1 instars at 0.27 mg dry wt/indiv.	<0.01	0.51
Psilochorema tautoru 4 Apr 71 and 28 Nov 71 values from Appendix 12b i.e. Apr : 2 F instars at 1.4 mg dry wt/indiv; 2 F-1 instars at 0.3 mg dry wt/indiv. and 1 F-2 instar at 0.06 mg dry wt/indiv. Nov : 13 F instars at 1.4 mg dry wt/indiv; 9 F-1 instars at 0.3 mg dry wt/indiv.	0.06	1.05
Anguilla dieffenbachii Refer to Appendix 14	0.39	0.39
Salmo trutta Refer to Appendix 14	0.51	0.51
SAPROPHYTES Not determined	ND	ND
c. Site 7 (watercress)		
PRODUCERS		
Nasturtium microphyllum Mean dry wt. two and three samples resp. (0.04 m^2) (Fig. 2.7). 4 Apr 71 : 50.5 g (43.6, 50.9, 57.1), 28 Nov 71 : 38.1 g (36.8, 39.4)	1260	950
Lemna minor Mean dry wt. of three samples (0.04 m^2) 4 Apr 71 : 2.0 g (1.4, 1.8, 2.8), 28 Nov 71 : 1.4 g (1.0, 1.3, 1.9).	50	35
PRIMARY CONSUMERS		
Lumbriculus variegatus Mean dry wt. of 34 samples (0.04 m^2) Nov 70 - Sep 71 (Appendix 12c) containing 0,0,0,3,0,1,9,6,1,50,5,15,101,188,308,23,17,10,8,71,11,60,8,3,12,10,13,10,0,5,5,3,4,3 indiv. at 0.46 mg dry wt/indiv.	0.31	0.31
Paracalliope karitane Mean dry wt. of 34 samples (0.04 m^2) Nov 70 - Sep 71 (Appendix 12c) containing 616 indiv. of mean length approx. 4 mm and 0.30 mg dry wt/indiv.	0.1	0.1
Paratya curvirostris Samples as for *Paracalliope karitane*, containing 50 indiv. C.L. 5.0-6.5 mm at 0.021 g dry wt/indiv; 18 indiv. C.L. 6.6-9.0 mm at 0.067 g dry wt/indiv.	3.2	3.2

APPENDIX 13 (cont'd.)

Component and basis for calculation	autumn 1971	spring 1971
Paranephrops planifrons Samples as for Paracalliope karitane, containing 18 indiv. C.L. 3.5-6.0 mm at 0.0073 g dry wt/indiv; 4 indiv. C.L. 6.1-10.0 mm at 0.061 g dry wt/indiv; 3 indiv. C.L. 10.1-15.0 mm at 0.51 g dry wt/indiv.	1.6	1.6
Megaleptoperla diminuta 4 Apr 71 and 28 Nov 71 values from 2 and 3 samples resp. (0.04 m^2) (Appendix 12c) i.e. Apr : total of 3 indiv. H.W. 1.6-2.0 mm at 7.1 mg dry wt/indiv; 2 indiv. H.W. 0.6-1.0 mm at 0.1 mg dry wt/indiv; Nov : total of 10 indiv. H.W. 1.6-2.0 mm at 7.1 mg dry wt/indiv; 6 indiv. H.W. 1.1-1.5 mm at 1.1 mg dry wt/indiv; 4 indiv. H.W. 0.6-1.0 mm at 0.1 mg dry wt/indiv.	0.6	0.6
Potamopyrgus antipodarum (excluding shell)* Mean dry wt. of 33 samples Nov 70 - Sep 71 (Appendix 12c)	32.6	32.6
Lymnaea columella (excluding shell)* Mean dry wt. of 39 samples, Dec 70 - Jan 72 (Appendix 12c) containing 7,0,0,2,0,1,4,3,5,9,1,5,2,5,3,2,3,9,11,3,16,3,2,22,24,8,0,2,3,2,0,2,28,19,17,2,8,1 indiv. of shell height as shown in Fig. 3.16 and weight including shell: Shell height 13 mm, 45 mg dry wt/indiv; 12 mm, 23 mg dry wt/indiv; 11 mm, 19 mg dry wt/indiv; 10 mm, 11 mg dry wt/indiv; 9 mm, 10 mg dry wt/indiv; 8 mm, 8 mg dry wt/indiv; 7 mm, 6 mg dry wt/indiv; 6 mm, 3 mg dry wt/indiv; 5 mm, 3 mg dry wt/indiv; 4 mm, 1 mg dry wt/indiv; 3 mm, 0.3 mg dry wt/indiv; 2 mm, 0.2 mg dry wt/indiv.	0.2	0.2
SECONDARY CONSUMERS		
Dolomedes n.sp. Mean dry wt. of 38 samples, Oct 70 - Sep 71 (Appendix 12c) containing 1 indiv. at 0.10 g dry wt/indiv; 8 indiv. at 0.009 g dry wt/indiv.	0.1	0.1
Anguilla australis schmidtii Mean dry wt. of 50 samples (0.04 m^2) from Oct 70 - Feb 72 containing 7 indiv. (Length 11.7-20.0 cm) of dry wt. 0.60 g, 0.69 g, 1.16 g, 1.45 g, 1.76 g, 2.0 g, 3.1 g.	5.5	5.5

APPENDIX 13 (cont'd.)

Component and basis for calculation	autumn 1971	spring 1971
SAPROPHYTES	0.05	0.05
Mean bacterial count 7.9×10^6/g wet wt. of watercress or 1.6×10^8/g dry wt. of watercress since dry wt. of watercress is 5% wet wt. (Appendix 4). Mean biomass watercress 1072 g dry wt/m^2 so bacterial count 1.69×10^{11}/m^2. Since 10^9 cells weigh 0.32 mg (dry wt.) in watercress (see Appendix 13a), bacteria are estimated to have a biomass of 54 mg/m^2.		

* Dry weight of gastropods (excluding shell) was taken to be 1.2 times the organic matter content of the gastropod (Methods, Part 5). For *Potamopyrgus antipodarum*, organic matter content was 9.7% of dry wt. including shell, and dry wt. excluding shell was thus 11.6% of dry wt. including shell. For *Lymnaea columella*, organic matter content was 25% of dry wt. including shell and dry wt. excluding shell was thus 30% of dry wt. including shell.

APPENDIX 14: Annual mean biomass of major species of plants and animals in Waikoropupu Springs, arranged according to trophic level occupied by the species. Only species that contribute more than 1% of the biomass to a given trophic level are considered. Only sites at which the biomass of the species of Primary Consumer exceeds 0.1 g dry wt/m^2 or the biomass of the species of Secondary Consumer exceeds 0.01 g dry wt/m^2 are considered. Indices of abundance are taken from Appendix 10. Biomass is expressed both as dry weight and as organic matter.
Abbreviations used: a.i. - abundance index; M - moss; L - liverwort; J. m. - Juncus microcephalus; M. e. - Myriophyllum elatinoides; N. m. - Nasturtium microphyllum, (em.) - emergent, (sub.) - submerged; est. - estimated.

Component and basis for calculation	Mean biomass (g/m^2)	
	dry weight	organic matter
PRODUCERS		
Bryophytes		
Cratoneuropsis relaxa and Fissidens rigidulus		
Area $\sim$90 m^2 (5% Springs area) $<$2 m deep. Mean biomass 1060 g dry wt/m^2 (mean of 4 values, Table 2.8) 54 g dry wt/m^2		
Area $\sim$70 m^2 (4% Springs area) $>$2 m deep. Biomass 725 g dry wt/m^2, est. from Table 2.8 29 g dry wt/m^2		
TOTAL	83	
Mean ash content 20.5% (6 determinations, Table 2.9)		66
Lophocolea spp., Neesioscyphus phoenicorhizus and Cyathophorum bulbosum		
Area $\sim$246 m^2 (14% Springs area) $<$4 m deep. Mean biomass 565 g dry wt/m^2 (Table 2.8) 79 g dry wt/m^2		
Area $\sim$100 m^2 (6% Springs area) $>$4 m deep. Mean biomass 424 g dry wt/m^2 (Table 2.8) 25 g dry wt/m^2		
TOTAL	104	
Mean ash content 27% (2 determinations, Table 2.9)		76
Angiosperms		
Juncus microcephalus		
Area $\sim$7% Springs (Table 2.6). Mean biomass 780 g dry wt/m^2 (3 determinations, Table 2.8).	55	
Mean ash content 14.5% (4 determinations, Table 2.9)		47

APPENDIX 14 (cont'd.)

Component and basis for calculation	dry weight	organic matter
Lemna minor		
Area 192 m^2 (11% Springs) (Table 2.6). Mean biomass 49 g dry wt/m^2 (5 determinations, Table 2.8).	7	
Mean ash content 13% (4 determinations, Table 2.9)		6
Myriophyllum elatinoides		
Area 285 m^2 (16% Springs area) (Table 2.6). Est. biomass 650 g dry wt/m^2 (Table 2.8).	104	
Mean ash content 11% (2 determinations, Table 2.9).		93
Nasturtium microphyllum		
Emergent. Mean area 289 m^2 (16% Springs area) (Table 2.6). Mean biomass 1072 g dry wt/m^2 (35 determinations, Fig. 2.7).		
172 g dry wt/m^2		
Submerged. Area 57 m^2 (3% Springs area) of which 54 m^2 (2.8% Springs area) at depth 2.5 m with est. biomass 750 g dry wt/m^2, and 3 m^2 (0.16% Springs area) at depth 6.5 m with est. biomass 250 g dry wt/m^2 (Table 2.8)		
21 g dry wt/m^2		
TOTAL	193	
Mean ash content 18% (11 determinations, Table 2.9)		159
PRODUCERS TOTAL	546	447
PRIMARY CONSUMERS		
Paracalliope karitane		
M/L<2 m deep a.i.4. Weighted mean M and L results (Appendices 12a,b) 1.16 g dry wt/m^2, 14% Springs area		
0.16 g dry wt/m^2		
M/L>2 m deep, *N. m.* (em.), *N. m.* (sub.) all a.i.3, and *M. e.* a.i.4, say, 0.1 g dry wt/m^2, 50% Springs area		
0.05 g dry wt/m^2		
J. m., a.i.4. say, 1.0 g dry wt/m^2, 7% Springs area		
0.07 g dry wt/m^2		
TOTAL	0.3	
Mean ash content 30% of dry wt (3 determinations - 26.0%, 31.5%, 31.1%)		0.2

APPENDIX 14 (cont'd.)

Component and basis for calculation	dry weight	organic matter
Paratya curvirostris		
M/L < 2 m deep, a.i.2 weighted mean M and L results (Appendices 12a,b), 0.34 g dry wt/m^2, 14% Springs area — 0.05 g dry wt/m^2		
M/L ≥ 2 m deep, a.i.1, say, 0.03 g dry wt/m^2, 15% Springs area — 0.005 g dry wt/m^2		
N. m. (emergent), a.i.2, mean value (Appendix 12c), 3.2 g dry wt/m^2, 16% Springs area — 0.51 g dry wt/m^2		
M. e., a.i.2, say 2.0 g dry wt/m^2, 16% Springs area — 0.32 g dry wt/m^2		
J. m., a.i.2, say 2.0 g dry wt/m^2, 7% Springs area — 0.14 g dry wt/m^2		
TOTAL	1.0	
Mean ash content 16% of dry weight (2 determinations - 14%, 18%)		0.8
Paranephrops planifrons		
M/L < 2 m deep, a.i.2, weighted mean M and L results (Appendices 12a,b), 10.1 g dry wt/m^2, 14% Springs area — 1.4 g dry wt/m^2		
M/L > 2 m deep, a.i.1, say, 1.0 g dry wt/m^2, 15% Springs area — 0.2 g dry wt/m^2		
N. m. (emergent), a.i.2, mean value 1.6 g dry wt/m^2 (Appendix 12c), 16% Springs area — 0.3 g dry wt/m^2		
M. e., a.i.2, say, 5.0 g dry wt/m^2, 16% Springs area — 0.8 g dry wt/m^2		
J. m., a.i.2, say, 5.0 g dry wt/m^2, 7% Springs area — 0.4 g dry wt/m^2		
TOTAL	3.1	
Mean ash content 32% of dry weight (2 determinations - 32%, 32%)		2.1

APPENDIX 14 (cont'd)

Component and basis for calculation	dry weight	organic matter
<u>Conuxia gunni</u> (excluding case)		
M/L<2 m deep, weighted mean of M and L values 0.89 g dry wt/m^2 (Appendices 12a,b), 14% Springs area	0.1	
Mean ash content 5.3% of dry weight (2 determinations - 5.0%, 5.5%)		0.1
<u>Potamopyrgus antipodarum</u> (excluding shell)		
M/L<2 m deep, a.i.5 or 6, weighted mean of M and L values 26 g dry wt/m^2 (Appendices 12a,b), 14% Springs area — 3.64 g dry wt/m^2		
M/L>2 m deep, a.i.3 say, 1.5 g dry wt/m^2, 15% Springs area — 0.23 g dry wt/m^2		
<u>N. m.</u> (em.), a.i.5, mean value 32.6 g dry wt/m^2 (Appendix 12c), 16% Springs area — 5.22 g dry wt/m^2		
<u>N. m.</u> (sub.), a.i.4, say, 1.5 g dry wt/m^2, 3% Springs area — 0.05 g dry wt/m^2		
<u>M. e.</u>, a.i.4, say, 2.6 g dry wt/m^2 16% Springs area — 0.42 g dry wt/m^2		
<u>J. m.</u>, a.i.5, say, 26 g dry wt/m^2, 7% Springs area — 1.82 g dry wt/m^2		
Without bryophytes and angiosperms, a.i.4, say, 2.6 g dry wt/m^2, 29% Springs area — 0.75 g dry wt/m^2		
TOTAL	12.1	
Mean ash content: 90% of dry weight incl. shell (6 determinations - 89%, 89%, 90%, 90%, 92%, 92%) or, by calculation, 17% of dry weight excl. shell (see Methods, Part 5), since dry weight excl. shell was assumed to be wt. of organic matter plus 20% of inorganic matter.		10.0
PRIMARY CONSUMER TOTAL	16.5	13.2

Component and basis for calculation	dry weight	organic matter
SECONDARY CONSUMERS		
Psilochorema tautoru		
M/L<2 m deep, a.i.3, weighted mean M and L values 0.24 g dry wt/m^2 (Appendices 12a,b), 14% Springs area — 0.033 g dry wt/m^2		
M/L>2 m deep, *N. m.* (em.), *J. m.*, *M. e.*, a.i.2, say 0.025 g dry wt/m^2, 54% Springs area — 0.014 g dry wt/m^2		
TOTAL	0.05	
Mean ash content 3.5% (3 determinations - 4.6%, 2.7%, 3.1%)		0.05
Anguilla australis schmidtii		
N. m. (em.). Mean value, 5.5 g dry wt/m^2 (Appendix 12c), 16% Springs area	0.88	
Mean ash content 6.9% (4 determinations - 9.0%, 6.8%, 5.9%, 5.9%)		0.82
Anguilla dieffenbachii		
1 indiv. length 90 cm (good condition) observed in Main Spring on 8 of 26 days' diving and 1 indiv. length 90 cm (poor condition), 1 indiv. length 45 cm observed on 1 day each. Allowing for cryptic habits of eels, assume that one eel is present continuously. Wet wt. about 2.59 kg (Burnet 1952). Assume dry wt. is 20% of wet wt. in the absence of other data (as for *S. trutta* - see below) i.e. 0.52 kg dry wt/1341 m^2. Assume same biomass of eels in Dancing Sands	0.39	
No ash determinations carried out on large eels and no data from literature. Ash content assumed to be 15%		0.33
Salmo trutta		
1 indiv. of est. wet wt. 2.5 kg present in Main Spring throughout study period. Dry wt. is 27.3% wet wt. (mean of 4 determinations on *S. trutta* of wet wt. 208 g, 273 g, 328 g and 401 g ex North Canterbury Acclimatisation Society) i.e. 681 g dry wt/1341 m^2. Assume same biomass of trout in Dancing Sands	0.51	
Ash content 26.6% (mean of 2 determinations on whole *S. trutta* - 22.4% (wet wt. 328 g), 30.9% (wet wt. 401 g))		0.37
SECONDARY CONSUMER TOTAL	1.83	1.57

Component and basis for calculation	dry weight	organic matter
SAPROPHYTES		
M/L < 2 m deep. No data for liverwort so assume same biomass as for moss (Appendix 13a) of 0.006 g dry wt/m^2. 14% Springs area — 0.0008 g dry wt/m^2		
M/L > 2 m deep. No data.		
N. m. (em.) See Appendix 13c, 0.054 g dry wt/m^2. 16% Springs area — 0.0086 g dry wt/m^2		
N. m. (sub.). No data.		
M. e. Mean bacterial count 1.3 x 10^5/g wet wt. of M. e. (2 samples) or 1.9 x 10^6/g dry wt. of M. e. since dry wt. of M. e. is 7% wet wt. (mean of 5 samples). Mean biomass M. e. 650 g dry wt/m^2 so bact. count 1.2 x 10^9/m^2. Since 10^9 cells weigh 0.32 mg dry wt. (Appendix 13a), in M. e., bacteria are estimated to have a biomass of 0.39 mg dry wt/m^2. 16% Springs area — 0.0001 g dry wt/m^2		
Without bryophytes and angiosperms. No data.		
TOTAL at least	0.01	
Ash content of 7% (*Escherischia coli*, Lamanna and Mallette 1959)		0.01